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Operational Based Vision Assessment

James Rader, PhD

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Final Report
for August 2008 to September 2013

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711th Human Performance Wing
School of Aerospace Medicine
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14. ABSTRACT
This report describes the history, design, and fabrication of the Operational Based Vision Assessment (OBVA) laboratory from the initial feasibility studies through the final 15-projector system. It describes the studies that were accomplished to define the system attributes and discusses the trades that were made in design parameters to complete the design and fabrication of the final laboratory. The OBVA laboratory integrated commercial-off-the-shelf simulation components into a high fidelity simulation laboratory to objectively assess the importance of visual characteristics to operational performance and the sensitivity of operational performance to these characteristics. This, in turn, may lead to changes in Air Force vision standards.

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High fidelity simulation, eye-limiting simulator, vision standards, high definition projection

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1.0 EXECUTIVE SUMMARY

The Operational Based Vision Assessment (OBVA) laboratory was developed to meet the requirement identified in the Air Force Medical Service Modernization Initiative Summary 20030820—"Super-Vision – wave-front guided PRK, LASIK, and future refractive and visual performance enhancing technologies"—guidance from the Air Force Surgeon General.

A capability was required to develop a high fidelity simulation laboratory to objectively measure visual performance outcomes applicable to a diverse range of present and future devices and surgeries. In addition, such a laboratory can also be used to assess the importance of visual characteristics to operational performance and the sensitivity of operational performance to these characteristics. Currently, Air Force visual standards dictate the criteria that pilot candidates and candidates for other aircrew positions must meet prior to entering training. However, there is no objective way to correlate those standards with pilot performance in an operational setting. The consequence is that the effects of waivers of standards or incorporation of new devices or surgeries remain unknown.

The United States Air Force (USAF) 311th Human Systems Wing Plans and Programs Directorate [now the 711th Human Performance Wing (711 HPW)] and the USAF School of Aerospace Medicine proposed, and the USAF Office of the Surgeon General, Directorate of Modernization elected to fund, the feasibility phase of the OBVA program. The purpose of the OBVA program was to investigate and validate the relationships between operational visual performance and current visual standards, possible future vision tests, and other measures of visual performance. This preliminary effort consisted of a study to determine the feasibility of using advanced display technologies. The primary goal of the program was to build a simulation laboratory to aid in establishing operationally based visual performance metrics. After a thorough review of appropriate agencies and institutions, the Plans and Programs Office determined that the National Aeronautics and Space Administration Ames Research Center's (NASA-ARC) would be the lead agent for the OBVA feasibility study because of its extensive expertise in human factors and simulation laboratories.

Work by NASA-ARC began in 2005. An Integrated Product Team (IPT) was formed. The IPT consisted of a wide range of Department of Defense participants to include Navy and Army research labs as well as the Air Force Research Laboratory (AFRL) at Mesa, AZ [now the Warfighter Readiness Research Division of the 711 HPW Human Effectiveness Directorate) and the Simulator System Program Office (now the Air Force Life Cycle Management Center, Agile Combat Support Directorate) at Wright-Patterson Air Force Base, OH. In addition, several internationally recognized vision scientists and several highly experienced Air Force pilots from different weapons platforms participated in the IPT. The IPT identified a set of candidate operational tasks that were likely to be sensitive to differences in visual function. The IPT surveyed existing simulation and display facilities. Current state-of-the-art simulator technologies that could be incorporated in a dedicated OBVA simulator were identified and examined. Next, the list of candidate operational tasks was refined, and specific technology requirements to study visual performance effects were identified. These technology requirements were used to down-select the available technologies, and several conceptual designs were produced. Two candidate systems were identified that would potentially provide at least 20/20 acuity, as well as several operational scenarios that could be used to examine differences in vision.

Based upon the work performed by NASA-ARC and AFRL for the OBVA program, BG Theresa Casey in August 2008 approved OBVA to enter into a Technology Development phase designed to quantitatively correlate the clinical measurements of vision with operational performance and further assess all of the technologies required by an OBVA system for their maturity. Upon successful completion of that phase of the program, BG James Carroll in March 2010 authorized OBVA to begin the Engineering and Manufacturing Development phase of the program. Design of the laboratory and the purchase of the simulator components began shortly thereafter. Assembly of the components began in May 2012. The OBVA laboratory achieved an initial operating capability on 28 September 2012 with the installation and initial checkout of a nine-projector system that met the requirements of the Capability Development Document. It achieved full operational capability on 30 August 2013 when the full 15-projector system became operational.

2.0 INTRODUCTION

2.1 Feasibility Study

The idea of using simulator technology to evaluate the effectiveness of clinical vision standards in operational-like scenarios has been pushed since the early 2000s. Col Doug Ivan (USAF Ret) pushed for acceptance of this technique, and this push, in conjunction with the Air Force Medical Service (AFMS) Modernization Initiative Summary 20030820 on "Super-Vision," was the genesis for the Operational Based Vision Assessment (OBVA) program. At the time, technology was not able to support the idea. Air Force pilots have an average visual acuity of 20/13, and simulator technology could not produce imagery that was better than the 20/60 – 20/40 range. That was not nearly good enough to test pilot acuity. Coupled to that was the fact that technology to reduce moving image blur, such as target aircraft movement, had not progressed to an acceptable level and was another limiting factor for a simulator designed to assess aircrew visual performance. Existing simulator display technology was acceptable for training but could not support the "eye-limited" performance required to research United States Air Force (USAF) vision standards. The vision standards that were developed for the biplane era in the 1920s and 1930s and had served well for the next 70 years would remain the standards for a while longer.

However, technology improved rapidly in a number of areas. High definition televisions with large pixel counts dramatically dropped in price. The technology carried over to digital projectors for theaters, and pixel counts for those projectors increased as prices decreased. The video game industry demanded realism and got it as programmers developed games that looked better than combat simulators. Computer speeds increased and storage prices dropped. The confluence of these technologies led to a June 2005 conference at Brooks City-Base, TX, attended by vision science specialists, pilot physicians, and simulation experts from the Department of Defense, private industry, and other government agencies. Their conclusions were that, while technology could not currently support an OBVA effort, the rate at which it was changing could make it possible in the near future. A feasibility study funded by the USAF Office of the Surgeon General, Directorate of Modernization and led by the National Aeronautics and Space Administration Ames Research Center (NASA-ARC) started to determine the system requirements that would have to be met if the OBVA laboratory were to be built. The study also examined the visual characteristics that could best be researched in a simulator setting and the

operational scenarios that could be presented to study those visual characteristics. The results of the first phase of the study presented in September 2006 concluded that the technology could present scenes at 20/15 equivalent resolution, operationally based tasks developed during the study could link to clinical vision tests, a consortium of organizations could develop an excellent working laboratory, and the cost was affordable.

During the first phase of the feasibility study, industry had further developed projectors that could display 8 million+ pixels, one of the key technologies needed to build a laboratory that could present scenes at eye-limiting resolution to pilots with the best vision. The second phase of the feasibility study allowed the team to more closely examine the findings of the first phase. The program purchased two Sony SRX projectors—one at NASA-ARC and one at the Air Force Research Laboratory's Human Effectiveness Directorate, Warfighter Readiness Research Division, Mesa Research Site (711 HPW/RHA)—to evaluate the projectors and develop potential operational vision tasks. The projectors were able to exceed NASA-ARC's original expectation and could show scenes at 20/10 resolution. Another technology that developed rapidly over the course of the second phase was warping and blending technology. Computer algorithms could take a flat image and alter it to be displayed on a spherical screen as it would be seen from the cockpit. In addition, other algorithms could be used to blend the overlapping images of several projectors into a seamless image that appeared as though it was generated by a single projector. The algorithms could perform these adjustments in a fraction of the time that a human could perform the task and with much greater precision. Computers and graphics processing units (GPUs) continued making gains in processing power. All of the elements needed for the OBVA laboratory to become a reality were coming to a confluence at the same time.

2.2 Technology Development

The results of the feasibility study were presented to the USAF Office of the Surgeon General, Directorate of Modernization in April 2008, and a Milestone A review that would allow the program to proceed to the acquisition phase of Technology Development was scheduled. The OBVA acquisition program began in August 2008 when BG Theresa Casey, the Milestone Decision Authority, gave approval at the Milestone A review to begin the Technology Development phase of the laboratory development. At that time, Gen Casey was convinced that technology had developed to the point that the OBVA laboratory could be feasibly fabricated using commercial-off-the-shelf (COTS) components that were either currently available in the marketplace or would soon be available. She was also convinced that a synthetic environment/simulator could show the link between clinical vision tests and operational visual performance.

The questions that needed to be answered during the Technology Development phase were as follows: Can all of these COTS elements be joined into a system to present an eye-limiting scene to pilots having 20/10 vision? Could the resultant system be used to host experiments that would establish a connection between visual performance in a clinical setting with operational visual performance?

The OBVA team began to define system parameters that, if met, would provide a "Yes" answer to the first question and to design and conduct experiments to answer the second question. The experiments were designed to investigate whether existing vision screening tests

involving color, contrast, and acuity could predict performance on operational tasks involving those aspects of vision.

The color task was designed by 711 HPW/RHA to measure the speed and accuracy of individual performance in identifying a combat scenario presented on a simulated fighter multi-function display that shows combat situations using color-coded symbology. Figures 1 and 2 show the task as it might appear to a person with normal color vision and to a deuteranope, respectively.

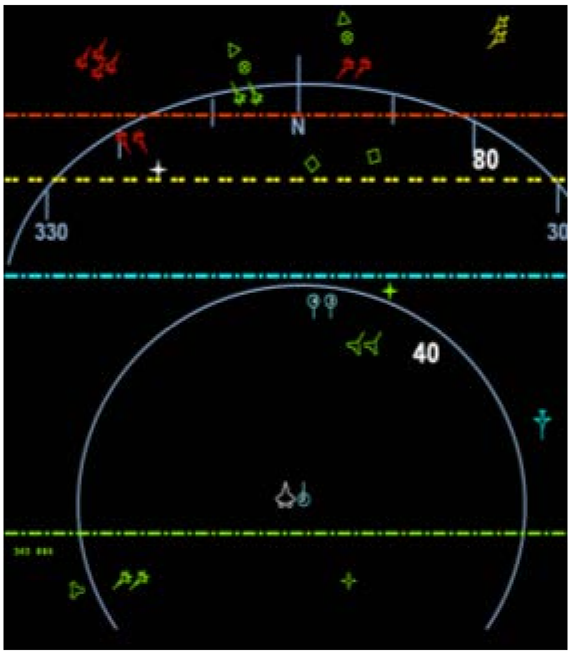

Figure 1. Combat scenario (normal color vision).

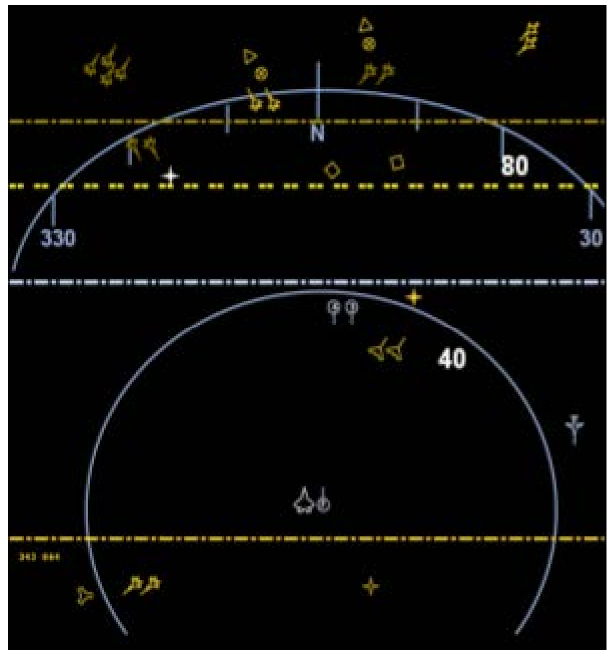

Figure 2. Combat scenario (deuteranope).

The two red aircraft near the upper left of Figure 1 are foes and have crossed the red line and may now be engaged by the green (friend) aircraft. Individuals with normal color vision may be able to take advantage of the color coding to more rapidly identify friend/foe and lines of engagement, while a deuteranope or deuteranomalous individual may have reduced performance. A small group of individuals, including a deuteranope and deuteranomalous individuals, was tested for their speed and accuracy in performing this task. Figure 3 shows a measure of performance for the deuteranope compared to color normals.

The results from these preliminary experiments concluded that when both speed and accuracy are considered, color deficient individuals (at least those who are severely color deficient) were less able than color normal individuals to perform this operationally relevant task.

The operational acuity task, designed by 711 HPW/RHA, required participants to determine whether aircraft at various simulated distances were coming toward the participant or going away from the participant (Figure 4).

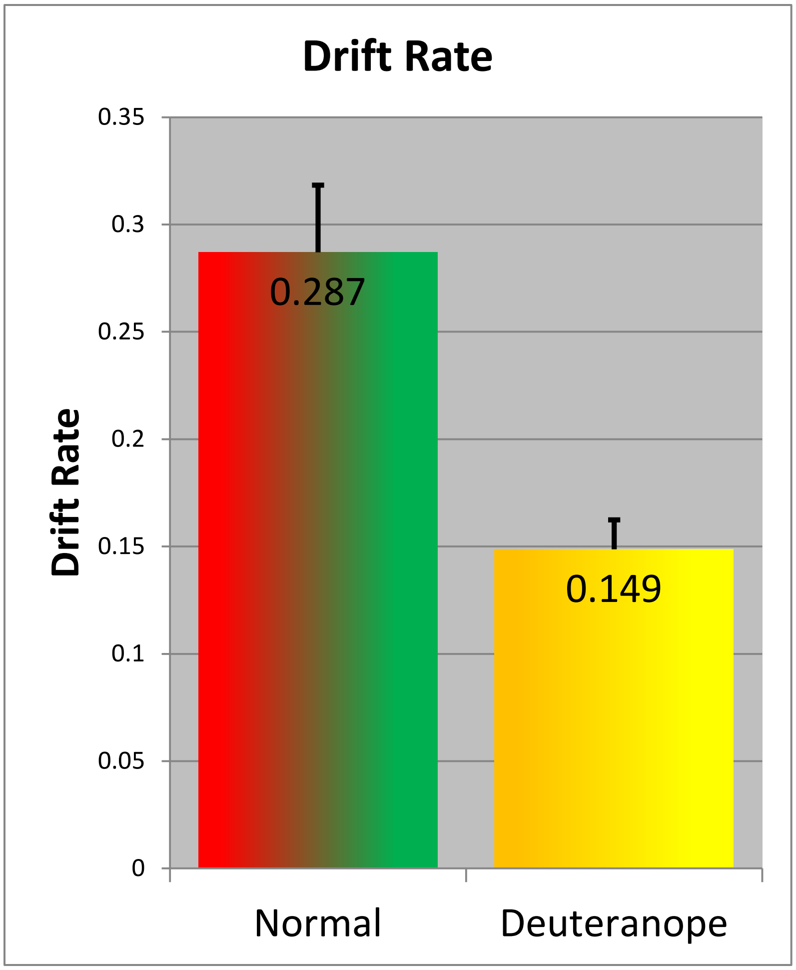

Figure 4. High contrast acuity test.

Performance on this task showed that participants with better acuity as determined by standard Snellen tests were better able to identify the correct orientation of the aircraft images. This is shown in Figure 5, where those subjects with the better acuity (the higher Snellen number to the right) were able to identify the aircraft orientation at longer ranges than those subjects with poorer acuity.

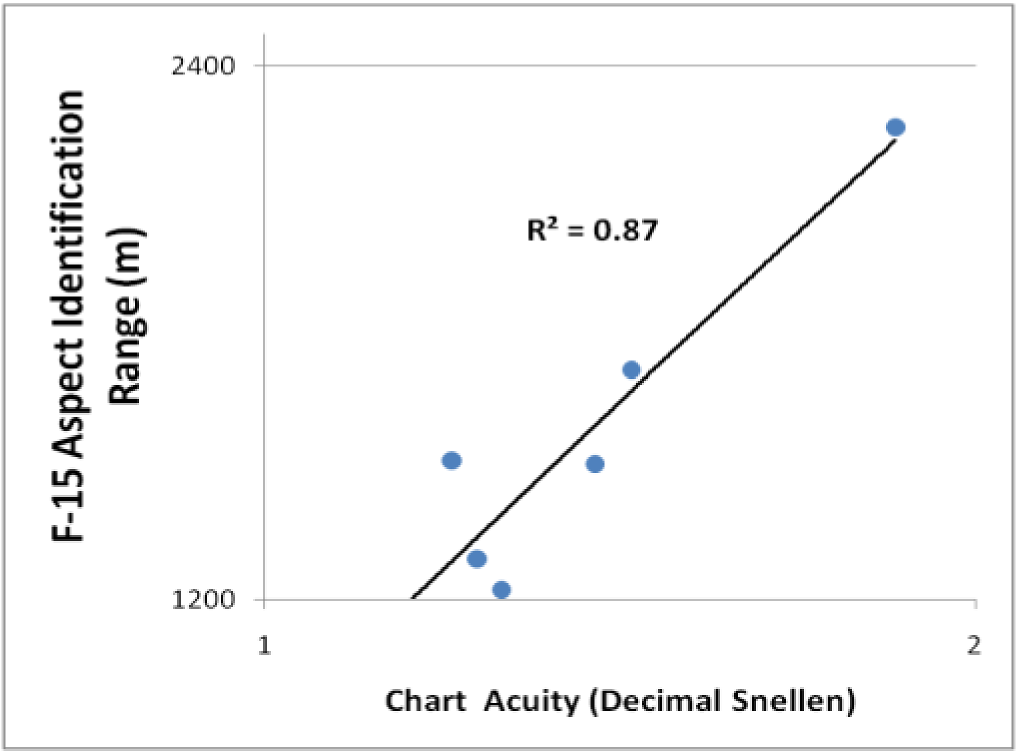

Figure 5. Results for high contrast acuity test.

Likewise, when the researchers simulated various visibility conditions to test contrast sensitivity as shown in Figure 6, the variations in individual performance that occurred led to the conclusion that there are differences in contrast sensitivity among individuals (Figure 7). At the same level of contrast, Subject B has much better sensitivity than Subject A (i.e., Subject B can see a target much farther away than Subject A.). Subject D sees the same size target as Subject C, but can do so in a much lower contrast environment. Lastly, Subject E has better acuity than Subject F in a high contrast environment (sunny day), but as the contrast is lowered (clouds/fog), Subject F performs much better (has better contrast sensitivity) than Subject E.

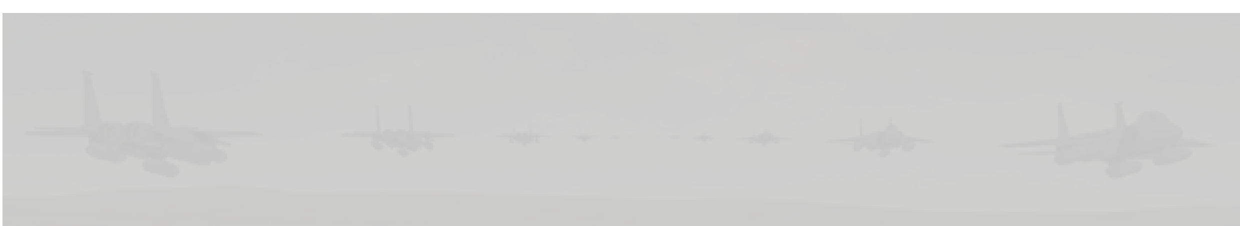

Figure 6. Low contrast test.

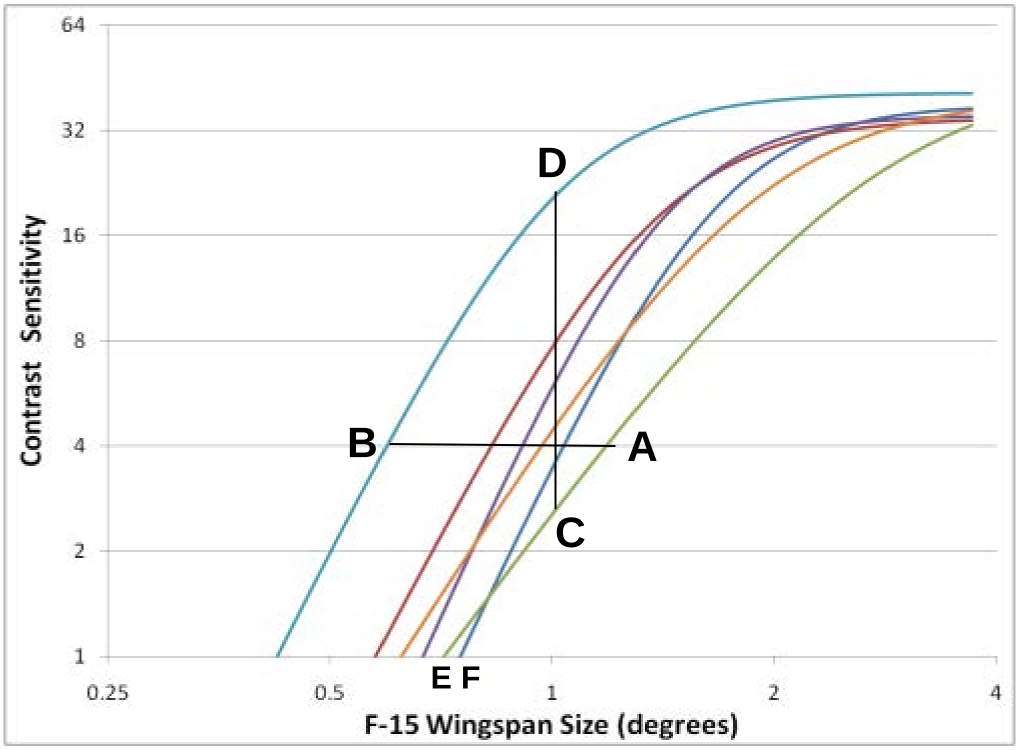

Figure 7. Results for low contrast test.

While the sample size for these experiments was small, they demonstrated a quantitative relationship between clinical visual performance and visual performance in an operational setting, meeting key exit criteria for the Technology Development phase of the program.

With these initial experiments demonstrating the relationship between clinical and operational visual performance, the team started defining system characteristics. To construct a system that was capable of meeting the OBVA program goals of presenting realistic, eye-limiting, operationally relevant scenarios to test visual performance, the team had to identify the system level performance that would achieve these goals and assign performance capabilities to each of the components. These goals were documented in the Capability Development Document (CDD) approved by BG James Carroll on 10 March 2010 (Appendix A). This document guided OBVA development and ensured leadership that, if the goals identified in that document were met or exceeded, the OBVA laboratory would successfully meet or exceed its requirements. Section 3.0 discusses the threshold (minimum acceptable performance) and objective (desired performance) requirements for each of the OBVA components as set forth in the CDD, how those requirements were chosen, and how the assembly of those components produced a laboratory that meets and often exceeds the goals of the OBVA program.

2.3 Engineering and Manufacturing Development

With the CDD completed, a Milestone B review was scheduled for 17 June 2010 at NASA-ARC with BG Carroll as the Milestone Decision Authority. Successful completion of the review would allow the OBVA project to enter the Engineering and Manufacturing Development phase, where components could be evaluated and ordered and fabrication of the laboratory could begin. At the review, Gen Carroll saw the progress that had been made for both component

performance and operational scenario development (i.e., quantitative relationship between clinical and operational visual performance). While he withheld Milestone B approval pending resolution of facility issues, he charged the team to proceed to finalize the design, evaluate the components to be used in the laboratory, and begin assembly and evaluation of engineering models of the laboratory. The team proceeded according to those instructions and held the Preliminary Design Review (PDR) 18-19 August 2010 followed by the Critical Design Review (CDR) 3-4 November 2010. The major result that came from those reviews was the decision to avoid a projector choice until the last possible moment. While the team had used the Sony SRX projectors through the feasibility study and the Technology Development phase, Barco was developing a new projector that also appeared to meet OBVA requirements. Because the schedule did not have laboratory fabrication beginning until late 2011 at the earliest, the team believed that monitoring Barco's on-going development and conducting tests on their engineering models would lead to healthy competition between the two manufacturers and provide OBVA with the best possible projector. Further discussion of the projector choice is in Section 3.1.2.

Several other decisions were also made at PDR and CDR. Scalable Technologies software was identified as the best solution for warping and blending of the OBVA imagery projected onto a spherical dome. The software is very adaptable and easy to use compared to other developers, and it is less expensive than other developers' software. The sources for the GPUs (Nvidia) and the host computer (Concurrent's iHawk) were identified. The projection screen field-of-view was set at 160° horizontal with the maximum possible vertical field-of-view split into 1/3 below the horizon view and 2/3 above the horizon view. More information on screen characteristics is presented below. Additionally, a projector tower and mounting plate design was presented by Mr. Leonard Best of L3 Communications (a 711 HPW/RHA contractor) that could be adapted to accommodate any of the projector candidates.

The time between the CDR and the beginning of OBVA fabrication in late 2011 was spent preparing for the Base Realignment and Closure, which affected two-thirds of the OBVA team; readying the facility to receive the laboratory; and designing and testing the image generator (IG) with its associated database and other OBVA subsystems at NASA-ARC. The NASA-ARC team made several important breakthroughs. First, they designed and fabricated the cockpit used in the OBVA laboratory. Second, they identified and obtained software for the aircraft equations of motion and installed it into the host computer. Third, they developed a method to download and store data from Google Earth to construct the database, and they constructed the database for the Sheppard Air Force Base (AFB), TX (Wichita Falls), area and began the database for the Elmendorf AFB, AK, area to include large variations in terrain elevation. Fourth, they connected these components together and began to project the image through two (and later four) Sony SRX projectors to refine the IG design and correct problems. This was a necessary step to ensure that, when the system was set up at Wright-Patterson AFB, problems would have already been corrected and installation would proceed smoothly and quickly. Fifth, they incorporated warping and blending into the system and projected the images on four sections of the final laboratory spherical screen. Sixth, they developed a way to measure the amount of latency (delay) in the system from the time the subject moves the cockpit control until the picture reaches the screen. This metric was required to ensure that system latency did not exceed 50 ms. This threshold requirement was set because excessive system latency will begin to degrade active flight control. Latency in the OBVA system is 32 ms, which is well below the threshold, and subjects will not experience any adverse effects from this minor

latency. Despite the careful work performed at NASA-ARC, there were problems that occurred when the first nine Barco projectors were turned on at the OBVA facility. These problems were related to the interaction between the IG and the projectors and the way the imagery is transmitted between the two. All of these problems were solved by making software changes within the warping and blending software, and these changes added nearly nothing to the overall latency measurement for the system.

3.0 MATERIALS AND METHODS

OBVA was conceived as a laboratory that would use state-of-the-art COTS technology to display the eye-limiting features necessary to perform vision research in an operational-like setting. While it looks like a training simulator, the features required in the OBVA laboratory would make it several technological leaps beyond state-of-the-art simulators. Few simulators used projectors that displayed the 8 million+ pixels that OBVA would use and none approached an eye-limiting resolution of 0.5 arcmin/pixel like OBVA required. That requirement, coupled with the requirements to present experimental subjects with a relatively realistic field-of-view and a viewing distance that approximated optical infinity, meant that the OBVA laboratory would use a large number of projectors that had to work seamlessly with associated computer hardware and software to display a scene that approximated the outside world and updated it 60 times per second based on pilot control movements. When initial discussions on OBVA began in 2005, that task was nearly impossible. Technological advances in the gaming and simulation communities currently make the task just difficult.

Several design considerations were incorporated into OBVA to improve performance and minimize costs. The first was to use only COTS hardware in the laboratory. Development of specialized hardware is both expensive and risky, and there was neither time nor funding to attempt this. The second was to develop the image generation software in-house. This resulted from a visit to the Virtual Reality Applications Center at Iowa State University, where Dr. James Oliver and Dr. Eliot Winer described their image generation work. They said that, although difficult, the in-house developed IG provided maximum flexibility to develop new experiments and applications because commercially developed IGs were fixed in what they could do and expensive to have changes made. The third design consideration was to use one central processing unit (CPU) to drive two GPUs which, in turn, would each drive a single projector. This concept would reduce hardware costs because fewer CPUs would be purchased and, more importantly, synchronization of all of the IG CPUs with the host computer would be easier to accomplish. Further discussion of the IG system is in Section 3.2.

3.1 Visual System

The visual system is the most obvious of the OBVA laboratory's systems because it is the largest system and the system that projects and displays the resulting visual imagery. It is composed of the projectors and the screen. Most of the CDD performance attributes address projector performance, but screen design was also an important factor in the visual system and will be discussed in this section as well. The final visual system attribute is blending. The design of the visual system involved many engineering trade studies that are shown in subsequent sections. Appendix B lists presentations that detail the methods and results of these engineering trade studies.

3.1.1 Screen. The OBVA screen was manufactured by Immersive Display Solutions from the Atlanta, GA, area. The screen was affected by two of the CDD performance attributes: viewing distance and field-of-view. The spherical screen has a 4-m radius, meeting the CDD threshold, and was molded in 12 fiberglass sections. The sections were assembled using a forklift and attached to a special structure in the rear of the screen; the sections are arranged in three horizontal rows of four columns (Figures 8 and 9). The 4-meter radius was chosen as a trade-off between far vision accuracy and system cost and space requirements. Clinical measurements often evaluate far vision using a 6-meter observer distance. However, when team members evaluated far vision performance using several visual cues, they found a minimal gain in performance from 4 meters to 6 meters. The increase in system cost and space requirements that results from increasing the screen size from 4 meters to 6 meters is due to the larger screen size. The height of the OBVA facility is 20 feet, and the 4-meter screen and associated structure barely fits in that vertical space. A facility with the capability to accommodate a 6-meter screen would have been difficult to find at WPAFB, and renovation would probably have been beyond the program budget. Additionally, because brightness is inversely proportional to the square of the projection area, the larger screen would have decreased the brightness of the image nearly 75%.

Figure 8. Assembly of OBVA screen.

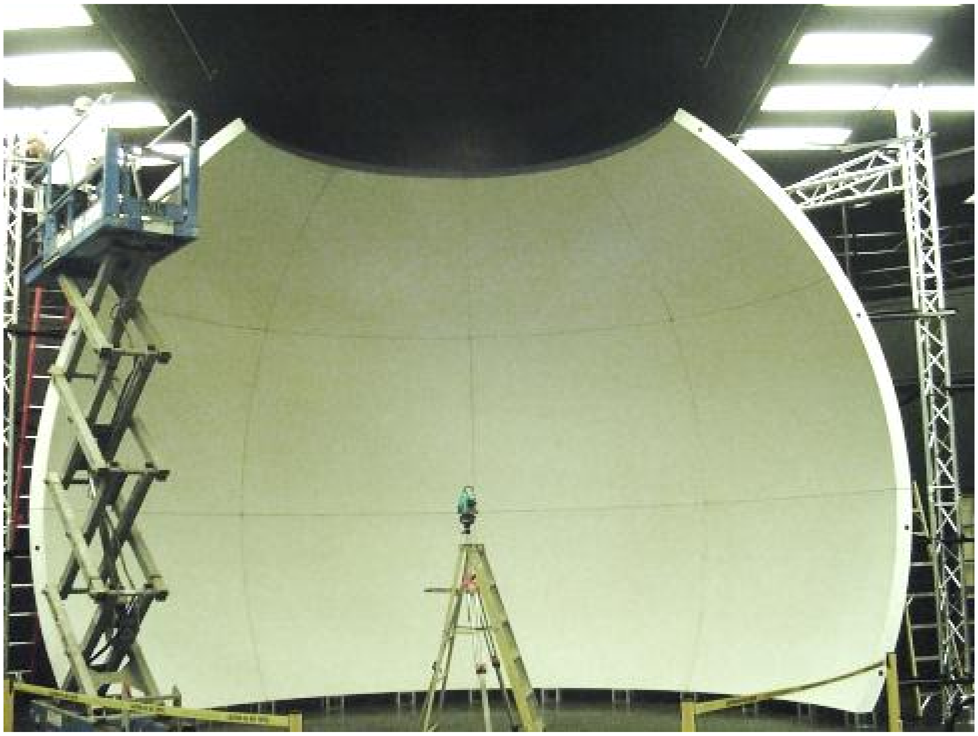

Figure 9. Assembled OBVA screen.

The total vertical field-of-view for the screen is 90° (30° down and 60° up). The total horizontal field-of-view is 160°. This easily meets the CDD threshold, but discussion below addresses the projector field-of-view parameters. Drywall compound was used to fill in the spaces in the dome and to smooth over any rough sections. The screen was painted with a flat latex paint made by Sherwin Williams, 7100 Arcade White. This color helped maintain the high luminance levels required while limiting light reflections that can be a problem with a spherical screen. The high luminance levels are required for testing acuity in daylight/high contrast conditions. The final screen assembly is shown in Figures 10 and 11.

3.1.2 Projectors. The OBVA team probably spent more time discussing projectors than any other component in the system. The recent emergence of flat screen televisions and projectors that use electronic chips rather than cathode ray tubes to display imagery has had a huge impact on both the consumer and simulation markets. High-end, quad high-definition (HD) (four times the pixel count of standard 1080p televisions) projectors first started to make their appearance just prior to the start of the OBVA program. Like other components of the OBVA system, these projectors have commercial applications far beyond the simulation community. They are increasingly used in movie theaters throughout the country. Improvements in the technology have been driven by commercial interests, and it was the desire of the OBVA team to reap the benefits of those improvements. To achieve a 20/10 resolution one pixel must not subtend an area larger than 0.5 arcmin. An initial analysis by the OBVA team concluded that shapes constructed of pixels of this size would be distinguished as shapes and not individual pixels by observers with 20/10 vision. They further concluded that, if possible, a pixel size of 0.35 arcmin provided an additional cushion for observers with the best vision. 711 HPW/RHA team members conducted extensive evaluations that confirmed this analysis. The results are depicted

in Figure 12 and show that the transition between display-limited visual performance and eye-limited visual performance occurs at a pixel size of approximately 0.5 arcmin (for high brightness and contrast conditions). The five subjects who were tested (left chart) were better able to distinguish shapes as individual pixels when the pixel size went above the 0.5 arcmin threshold. When pixel size was below that threshold, subject performance remained nearly constant as they perceived shapes themselves and not the pixels that made up those shapes. The same trend is evident in the test results for one subject (right chart).

Figure 10. OBVA screen being filled with drywall compound.

The spatial resolution requirement of 0.5 arcmin per pixel drove the team to consider only quad HD projectors capable of delivering over 8 million pixels per projector. While smaller HD projectors could meet the requirement, the number of projectors required to cover the field-of-view grew unwieldy to 60 or more, creating a nightmare to link all of the projectors together and increasing the number of blend zones between projectors (which due to overlapping would increase the number of projectors required to achieve the desired resolution). The three quad HD projectors under consideration were the Sony SRX, Barco SIM10, and JVC. JVC was eliminated almost immediately because it did not meet the threshold for the red chromaticity gamut that was required to display aviation red, and JVC did not have lenses available that would match the throw ratios required by the design. While both the Sony and Barco met the chromaticity requirements, the Sony was better than the Barco, especially in the display of aviation red.

Figure 11. Completed OBVA screen.

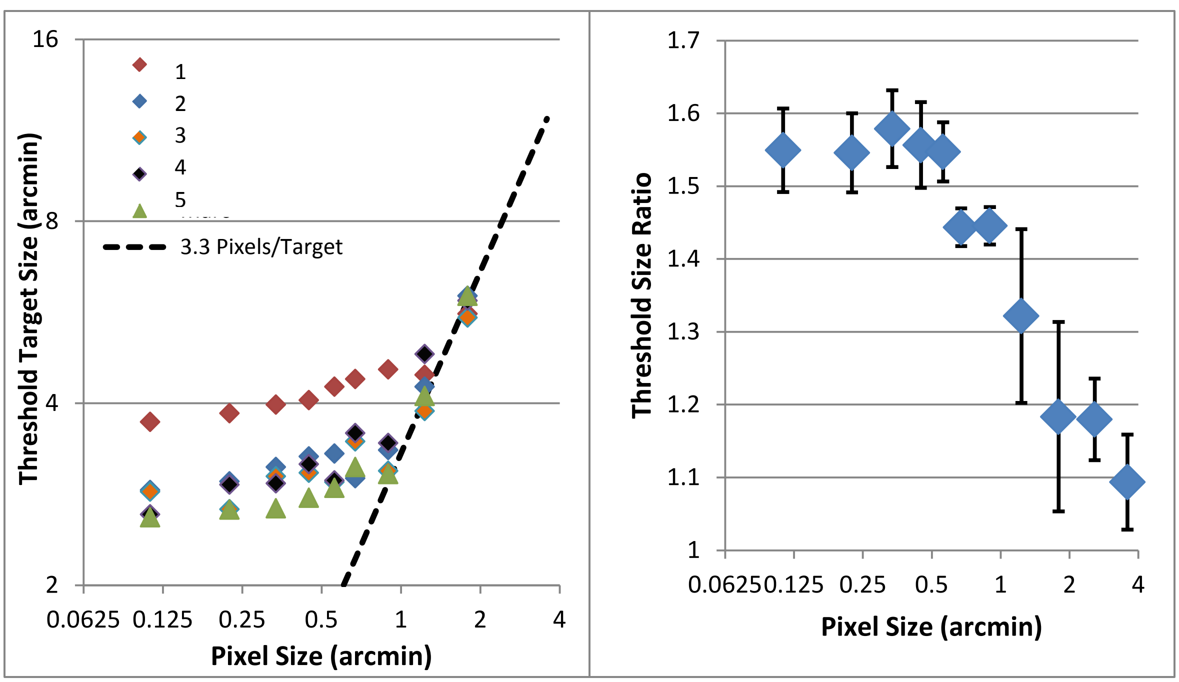

Figure 12. Results of pixel size experiments.

Both the Sony and Barco meet the 60-Hz refresh rate threshold, which is the highest refresh rate available for quad HD projectors. HD projectors could meet the objective rate of 120 Hz, but have the linkage problem noted above. Both projectors met the threshold requirements for temporal resolution to reduce smear that will occur in high motion scenarios, but use different techniques to meet the requirements. The Barco uses a mechanical shutter that is integrated within the projector, while the Sony uses a liquid crystal display (LCD) shutter manufactured by a third party and added to the projector. In addition to light loss resulting from any kind of shuttering, the LCD shutter loses an additional 30% of light over mechanical shutters. Additionally, the quality of the LCD shutter degrades over time and may cause shifts in color appearance. Because of these issues, the shutter needs to be replaced at 1000-hour intervals at a cost of $5K per projector. This is not a trivial amount for the OBVA maintenance budget and was a strike against the Sony projector.

Each projector has a field-of-view of approximately 20° vertical by 32° horizontal. The 15 projectors can be arranged in a variety of ways to obtain fields-of-view that are dictated by the experiment being conducted. The current three rows by five columns arrangement provides a field-of-view of approximately 55° vertical by 155° horizontal. By rearranging into a five rows by three columns configuration, the 80° by 80° threshold is met, but researchers at the OBVA laboratory believe that configuration will not prove as useful for experiments as the current configuration.

Both projectors easily exceeded the objective luminance requirement of 200 cd/m^2, with the Sony measured at almost 700 cd/m^2 and the Barco around 450 cd/m^2 depending on which projector was tested. The Sony was higher because it has two 2000-W xenon lamps while the Barco has only one. While each projector individually exceeded the objective for checkerboard contrast ratio, when this attribute is applied to the system as a whole where there are 15 projectors shining light into a spherical dome and a lot of reflection, engineering trades enter the picture. In this case, the trade-off is between luminance and contrast. The contrast decreases when a large number of projectors are arranged to shine into a spherical dome because of the large amount of light reflecting in the dome as noted above. This reflectance can be decreased by painting the dome a darker color. The OBVA team evaluated shades that were darker than the one finally selected, but with those colors the luminance as measured at the screen decreased by 30%-50%. A decrease of luminance by such a large amount, while it would have improved contrast, was deemed unacceptable, and the OBVA laboratory has higher luminance at the expense of contrast.

Both projectors met the bit depth requirement, with the Sony meeting the threshold and the Barco meeting the objective. The Barco projectors chosen for OBVA met color, luminance, and spatial resolution uniformity threshold values specified in the CDD.

The Sony SRX projector has been commercially available for several years, and the program had purchased two of them for our feasibility phase. The OBVA team had considerable experience running the projectors and was very familiar with its strengths and weaknesses. In addition, the team had visited numerous other facilities that used the projectors in their work and had the perspective of those facilities as well. The Barco SIM10, by contrast, was in its final test phase as it came time to make a projector decision. On paper it looked comparable to the Sony—better in some areas, a little weaker in others. But there was no opportunity at the time of the PDR to evaluate a full-rate production model and test it for our requirements. The team was able to thoroughly evaluate two prototype SIM10 projectors and was assured by Barco that the production model would be better. The projector display worked well, but there were problems

getting the IG and prototype projector to work together to display a full 10M pixel image. The decision was made to continue carrying both projectors forward as candidates until the last possible moment. In the end, the problems and cost associated with the Sony shutter as well as the high quality of the new Barco SIM10 led to selection of the Barco as the OBVA projector with the caveat that the OBVA team would test production model Barco projectors and, if they failed our testing, we were not obligated to purchase from Barco. The Barco projectors passed and are the projectors being used in the OBVA laboratory.

The projectors were mounted on structures that were fabricated, powder coated, and partially assembled at the L3 Communications facility in Mesa, AZ. The partially assembled structures underwent final assembly at the OBVA laboratory at Wright-Patterson AFB, and the projectors were then mounted onto the structures. These events are shown in Figures 13 through 15.

Figure 13. Initial view of OBVA projector structures.

Figure 14. Partial assembly of OBVA projector structure.

Figure 15. Completed OBVA projector structure with some projectors mounted.

3.1.3 Blending. As noted above, one of the technologies that has made rapid advances in the past few years is the blending of the images generated by several projectors into an image that looks uniform. When several projectors are used to generate pieces of a larger image, the display of those images on a screen contains obvious overlap regions (Figure 16). These overlap regions are unacceptable even in training simulators, where image quality is less important, and definitely unacceptable in an eye-limiting research laboratory. The light in the overlap regions can be adjusted to make the image look as though it was generated by one projector. If done manually, it takes hours to make the adjustments and additional time when the projectors get out of adjustment—which they will. The advances in technology have enabled these adjustments to be done automatically, taking only minutes, and when the projectors get out of adjustment, valuable experiment time is not lost readjusting the projectors to provide a blended image (Figure 17).

After much market research, the OBVA team determined that the blending solutions provided by Scalable Display Technologies of Cambridge, MA, were easiest to implement and quick to implement and provided a seamless image across all projectors. Their software-based solution was chosen to implement the blending for OBVA. Some adaptation of their COTS product was required because of the complexity of the OBVA projectors and associated IG configuration. The result is a high-quality, blended composite image with excellent warping accuracy. The entire calibration process takes 15 minutes or less, easily exceeding the objective value of this system attribute.

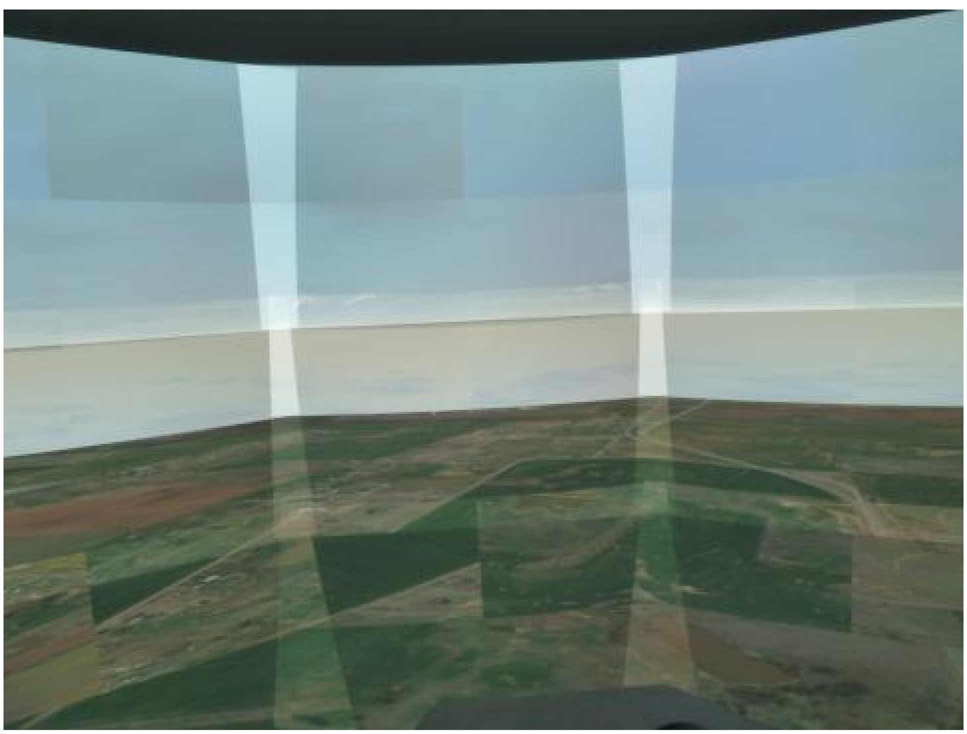

Figure 16. Unblended images from 9-projector configuration.

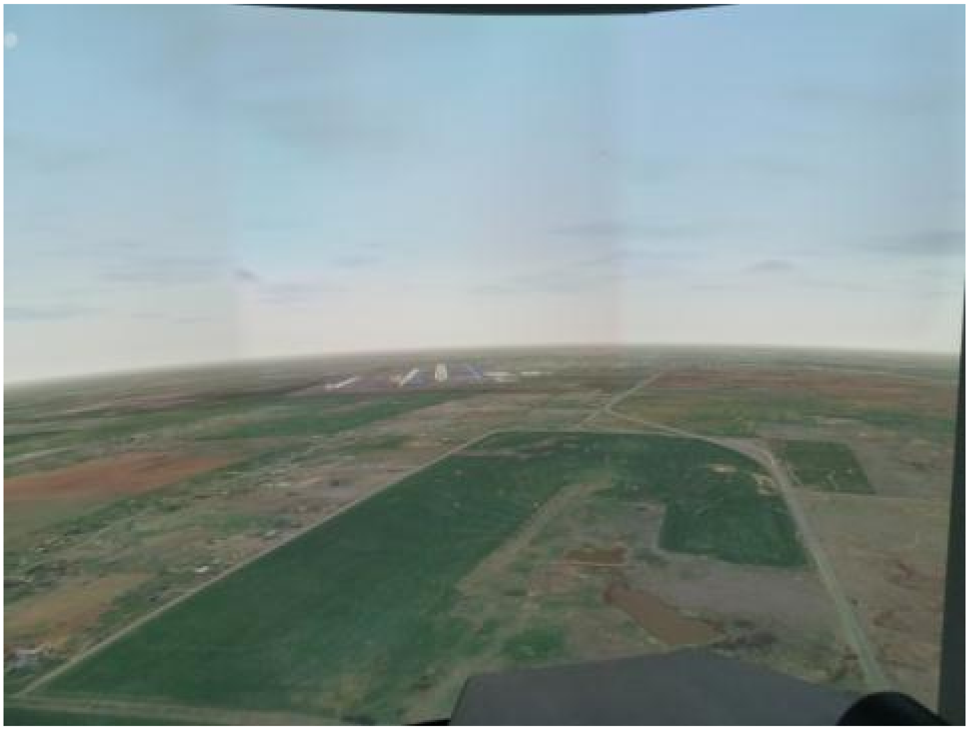

Figure 17. Blended images from 9-projector configuration (same scene as Figure 16).

3.2 Image Generation and Host Computer Systems

The computers and GPUs powering the IG system have to at least match the capability of the visual system/projectors to meet the system requirements. Each of the IG channels is capable of the 60-Hz refresh rate required by the CDD. The IGs can actually support the objective refresh rate of 120 Hz, but that capability cannot be supported by the projectors. Until quad HD projectors that can refresh at a rate of 120 Hz become available in the market, the IG will run at less than peak performance.

Getting the IG, as currently constructed, to support the spatial resolution and update requirements has been problematic when it concerns the database. The database is the land area around which the subject “flies.” It may contain runways, buildings, mountains, and other landmarks. To achieve the stringent spatial resolution and update requirements means updating an extremely large amount of data (most of which is not being currently used) 60 times per second. There are two workaround solutions for this problem. The first is to reduce the resolution of most of the database, which is not of interest to the current experiment. This is currently being done but somewhat defeats the purpose of having an eye-limiting device. The second is known as paging, which updates only the area of the database currently displayed and a small area around the current display. As the area to be displayed changes because of movement of the aircraft, new portions of the database are paged into the display as they are needed. This technique dramatically decreases the size of the scene (and consequent number of pixels) that needs to be updated at any one time and can incorporate much higher resolutions than the first technique. While not currently available in the OBVA IG structure, paging is scheduled to be incorporated into the IG at the earliest opportunity and allows OBVA to meet the requirement for

online disk storage (speed). For objects other than the database, such as other aircraft (whether friendly or hostile) or ground-based targets, spatial resolution and update requirements present no problems because those objects typically require less data to construct and even the most eye-limiting of these objects can be updated at very fast rates.

Channel synchronization has been the second problem for the OBVA IG system. Synchronization is required to ensure that all of the projectors display their part of the current scene at exactly the correct instant. If that does not happen, the picture, when moving, appears to tear across projector boundaries, which is a distracting artifact when performing visual tests. The problem has been isolated by the OBVA team to the Nvidia GPUs. The OBVA system uses an external signal to initiate the synchronization process. That signal stays intact until it reaches the GPUs and the signal coming out of the GPUs is no longer in sync. Nvidia's products were advertised to support such synchronization; Nvidia is aware of the problem and is working to deliver a software fix for the problem. Initial OBVA experiments will be able to be accomplished despite this problem.

In addition to concerns with some of the requirements discussed above, the IG system either does not meet some of the other requirements or they have been ignored to give the OBVA laboratory the flexibility it needs to be a good research tool. These requirements and explanations for why they have not been met are discussed below. It must be noted that these are system attributes and not key performance parameters or key system attributes and do not prevent the OBVA laboratory from performing its mission of relating clinical vision testing to operational visual performance.

Full Scene Subpixel Anti-Aliasing: Although the Quadroplex 7000 GPUs are capable of 16-subpixel full scene anti-aliasing (FSAA) in hardware for lower resolution displays, no FSAA can be enabled when one CPU is driving two Barco SIM10 projectors because there is not enough available GPU memory. This issue was discovered the first time the team tried driving two quad HD projectors. There is also insufficient GPU memory to drive two quad HD projectors at a coarser level of anti-aliasing (2x-FSAA). The team did confirm that there is sufficient memory to do 4x-FSAA (which looks pretty good) when using one CPU to drive one quad HD projector, and in the future, there may be an upgrade to add additional CPUs so that one CPU drives one quad HD projector. However, it is important to note that with 0.5-arcmin pixels, the presence of "jaggies" that anti-aliasing is designed to ameliorate is no longer a noticeable artifact.

Common Image Generator Interface (CIGI) Protocol: The team decided not to use the industry standard CIGI protocol because OBVA was expected to have a more research and development type interface where the host could more easily generate shader control parameters and other custom packets not readily supported in CIGI except as custom packets there as well. The reconfigurable image generator can be made to support the CIGI protocol but would require an update to do so. It would be relatively straightforward to add if OBVA ever needed this capability. However, a critical component of this system attribute was real-time data capture, which is a capability that was incorporated into the delivered system.

All other requirements placed on the IG and host computer system have been met or exceeded.

The IG computer equipment is shown in Figure 18.

Figure 18. OBVA image generator system.

3.3 Cockpit System

The goal for the cockpit system was to build a generic cockpit that would have the look and feel of a fighter aircraft without being platform specific. All Air Force pilots have training experience in T-38 aircraft, and flying a single-seat, agile aircraft simulator is something all pilots will have in common. The goal for proceeding in this manner was to provide subjects with a realistic feel so that the flight experience would not be a distraction from the visual experiments that would be taking place. The pilots should be focused on the task at hand, which is the visual task, and not be concerned about flying the simulator. The cockpit was designed and constructed by team members at NASA-ARC and shipped to Wright-Patterson during fabrication of the laboratory.

While not contained in the system attributes, the inceptors, the simulated aircraft controls that provide information to the IG system on the aircraft movement, were deemed an important aspect of the design to provide the simulator with as realistic a feel as possible. The NASA-ARC team has had experience with different inceptor manufacturers and recommended Wittenstein from Germany as the manufacturer with the smoothest and most realistic inceptors, and their F-16 inceptors were chosen for OBVA. They are shown in Figure 19.

Based on the experience of 711 HPW/RHA, we decided early in the program that a motion platform was not desired for the OBVA cockpit. The reason for this decision is that a motion-based simulator is very expensive, and that motion, which is usually not incorporated into fighter aircraft training simulators, would not add to the visual experience and might, in fact, detract from that experience.

Figure 19. F-16 inceptors.

The OBVA team also decided to incorporate a single, reconfigurable color display (glass cockpit) into the cockpit. This touchscreen monitor is used to display the instrumentation in the cockpit and has the ability to change the configuration of the instrumentation to simulate different aircraft. For the cockpit, the team purchased a 24-inch color touchscreen monitor to display the instrumentation. This monitor can be reprogrammed to display different sets of instrumentation if called for in other experiments. In addition, there is a 23-inch monitor that can be used to simulate a helicopter chin window and display ground scenes if researchers need to reconfigure the cockpit to simulate rotary wing landings (an operational scenario being considered because it may be related to contrast sensitivity). The assembled cockpit is shown in Figure 20 and a detailed view of the glass cockpit monitor shown in Figure 21.

The OBVA laboratory is also equipped with standard aviation headphones for communication between the cockpit and console operator. Not only does this simulate a real-world environment, but it helps eliminate the projector noise the subject may be exposed to in the rotunda where the projectors, screen, and cockpit are located.

Other preferred options for the OBVA laboratory are the ability to interface with platform-specific cockpits and the ability to perform eye tracking. The interface ability has not been tested at this time, as there has been no need for this feature. While eye tracking was a preferred option, current experiments do not require eye-tracking capability, and it will be incorporated into the laboratory at a date in the future when it is required. The OBVA key performance parameters specifically identify acuity, contrast, and color as the aspects of vision to be tested in the OBVA laboratory.

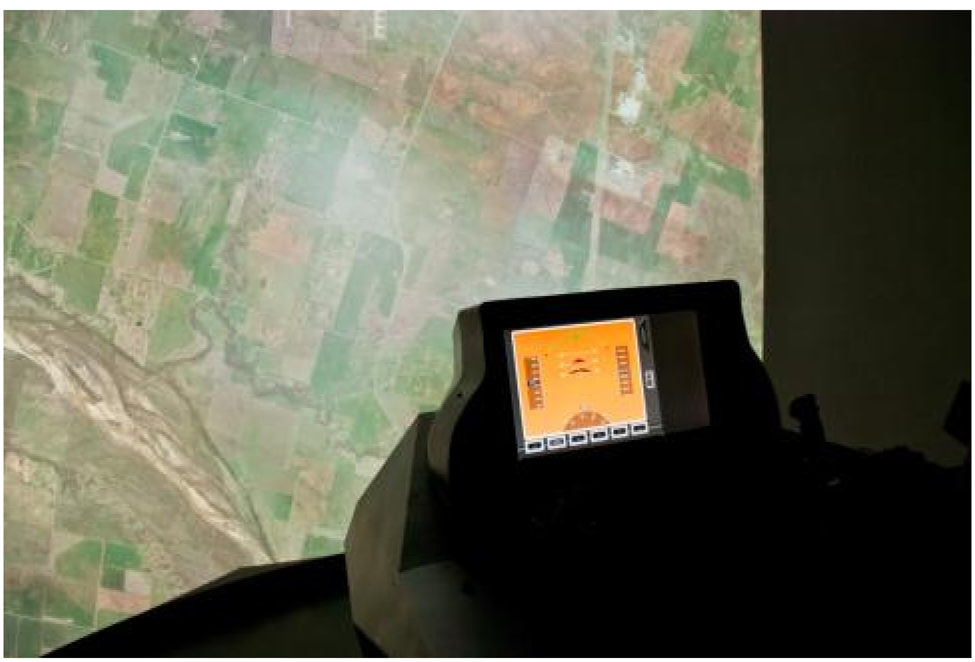

Figure 21. Reconfigurable cockpit monitor.

3.4 Data Collection and Laboratory Control Systems

There were no requirements for the data collection system other than it be compatible with the other components of the OBVA laboratory. It was noted that such a system could be procured commercially and it was. The system will be used to record results from experiments conducted in the OBVA laboratory. The collection system selected was a commercial 500-GB hard drive.

The laboratory control room was not specified in the original CDD but was added upon a recommendation from NASA-ARC that a control room would be beneficial to track other laboratory systems and subjects as experiments were conducted. The projectors and the image generation system can both be turned on from the control room. Cameras can relay to the control room views from various parts of the rotunda, where the screen, cockpit, and projector assembly are located, so the investigators can see a partial picture of the scene the subject sees. The investigators in the control room can communicate with the subject while an experiment is being conducted by means of a communication subsystem. Finally, the control room interfaces with the data collection system, and sequences of the experiments can be played back in the control room after the experiment is complete. The control room is shown in Figure 22.

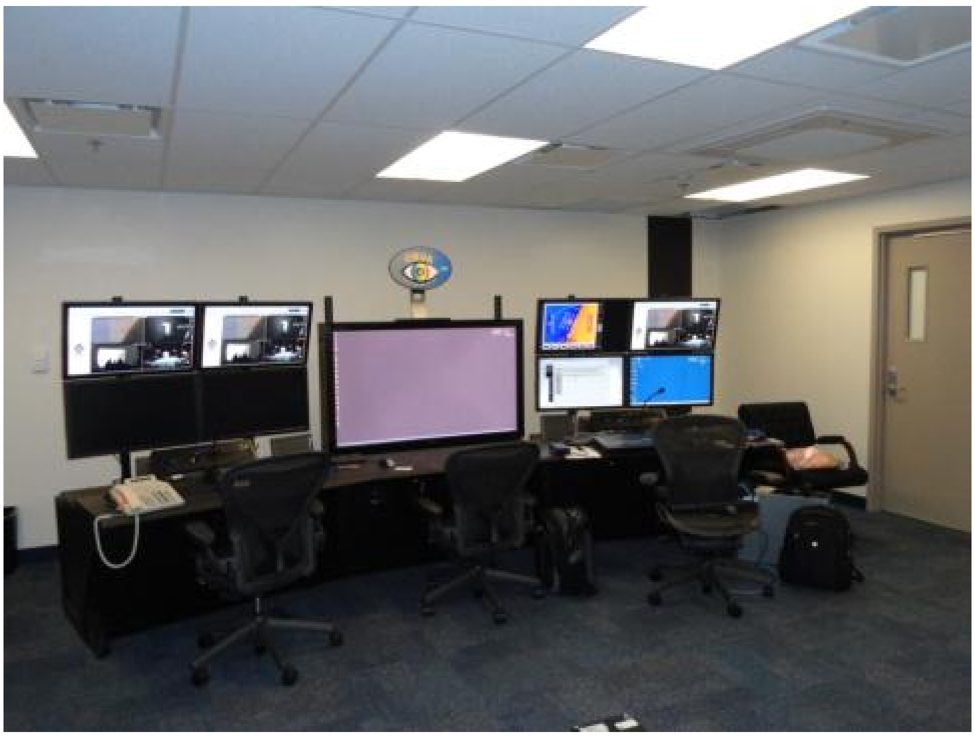

Figure 22. OBVA control room.

4.0 RESULTS

The OBVA laboratory was completed with an initial operating capability of nine projectors on time and nearly $210K under cost. Currently, the laboratory has its full complement of 15 projectors, and we are beginning experiments on the effects of color deficiencies on certain aspects of landing performance. Figures 23 and 24 show the dome with the full complement of 15 projectors turned on and a panoramic view of a scene from the area near Elmendorf AFB, AK, as displayed by the 15 projectors, respectively. The resulting imagery seamlessly blends 150 million pixels that are updated 60 times per second at photopic (daylight) luminance levels. This level of resolution is equivalent to 70 HD televisions. When compared to a typical movie theater, the OBVA laboratory has over 16 times the resolution in a comparable field-of-view, an order of magnitude greater brightness, and an update rate that is 2.5 times faster. To our knowledge, this is the highest resolution, largest field-of-view simulation system anywhere in the world.

Figure 23. Full 15-projector scene displayed on screen.

Figure 24. Panoramic view of 15-projector scene near Elmendorf AFB, AK.

With the exception of those attributes noted in Section 3.0, the OBVA laboratory meets or exceeds all of the system attributes put forth in the CDD. Some of the attributes that were not met (CIGI protocols) were the result of conscious decisions made by the OBVA team to change the course of the development. Even then, that attribute was not a major driver of the OBVA performance. The other attributes not met (16-subpixel FSAA; checkerboard contrast ratio with 15 projectors) were because of the laboratory design configuration and engineering trades. The capabilities provided by the OBVA laboratory in terms of level of resolution, seamless wide field-of-view, color gamut, color and luminance uniformity, and real-time data collection are unprecedented and provide the USAF with a world-class flight simulation facility for vision research. A similar system, to our knowledge, does not exist anywhere else in the world. The

successful development of the OBVA laboratory will enable AFMS to generate data that will be used to inform USAF aircrew vision standards. The OBVA laboratory provides AFMS with a powerful tool to identify aspects of vision that may contribute to the success of the mission, and help ensure the survivability of aircrew.

APPENDIX A

OBVA Capability Development Document

CAPABILITY DEVELOPMENT DOCUMENT

FOR

OPERATIONAL BASED VISION ASSESSMENT (OBVA)

Increment: I

ACAT: Non-ACAT

Validation Authority: Assistant Surgeon General, Modernization

Approval Authority: Assistant Surgeon General, Modernization

Milestone Decision Authority: Assistant Surgeon General, Modernization

Designation: Joint Information

Prepared for Milestone B Decision

Date: 21 September 2009

5 Mar 2010

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Executive Summary

This Capability Development Document (CDD) meets the requirement identified in the AFMS Modernization Initiative Summary "Super-Vision – wave-front guided PRK, LASIK, and future refractive and visual performance enhancing technologies", guidance from the Air Force Surgeon General, and technological advances in visual display technology.

A capability is required to develop high fidelity vision simulation to objectively measure visual performance outcomes applicable to a diverse range of present and future devices and surgeries. In addition, such a simulation can also assess the importance of visual characteristics to operational performance and the sensitivity of operational performance to these characteristics. Currently, Air Force visual standards dictate the criteria that pilot candidates must meet prior to entering Undergraduate Pilot Training. However, there is no objective way to correlate those standards to pilot performance in an operational setting. The consequence is that the effects of waivers of standards or incorporation of new devices or surgeries remain unknown.

The United States Air Force 311 Human Systems Wing Plans and Programs Directorate (now the 711 HPW/XP) and the USAF School of Aerospace Medicine (USAFSAM) proposed, and the USAF Office of the Surgeon General, Directorate of Modernization (AF/SGR) elected to fund the feasibility phase of the Operational Based Vision Assessment (OBVA) program. The purpose of the OBVA program is to investigate and validate the relationships between operational visual performance and visual standards, proposed future tests, and other measures. This preliminary effort consisted of a study to determine the feasibility of using advanced display technologies. The primary goal of the program is to establish operationally based visual performance metrics. After a thorough review of appropriate agencies and institutions, it was determined by XP that because of NASA Ames' extensive expertise in human factors and simulation laboratories, NASA would be the lead agent for the OBVA feasibility study.

Work by NASA Ames began in 2005. An Integrated Product Team (IPT) was formed. The IPT consisted of a wide range of DoD participants to include Navy and Army Research labs as well as labs from the Air Force Research Laboratories (AFRL) at Mesa, AZ and Wright-Patterson AFB. The IPT identified a set of candidate operational tasks that were likely to be sensitive to differences in visual function. The IPT surveyed existing simulation and display facilities. Current state-of-the-art simulator technologies that could be incorporated in a dedicated OBVA simulator were identified and examined. Next, the list of candidate operational tasks was refined, and specific technology requirements to study visual performance effects were identified. These technology requirements were used to down-select the available technologies, and several conceptual designs were produced. Two candidate systems were identified that would potentially provide at least 20/20 acuity, as well as several operational scenarios that could be used to examine differences in vision.

Based upon the work performed by NASA (Ames) and AFRL for the OBVA program, we entered into a Technology Development phase designed to quantitatively correlate the clinical measurements of vision with operational performance and further assess all of the technologies

required by an OBVA system for their maturity. This work has provided confidence that the objectives of the program can be achieved for the following reasons:

a. NASA and AFRL have assessed synthetic environment technologies and demonstrated that such environments can be used to achieve a level of realism equivalent to 20/10 vision (or 0.5 arc-minutes/pixel). At least two projector manufacturers have technology capable of producing this resolution. Additionally, image generators to display simulated tasks exist today as does the technology to blend the images of several projectors into a single, coherent picture.

b. In coordination with elements of 711 HPW/RH and the 677 AESG, NASA has developed a series of operationally-based tasks linked to clinical vision tests. Scenarios developed from these tasks can be used within the synthetic environment to demonstrate the correlation and quantify the level of correlation between vision and operational aviation performance.

c. The IPT has identified current simulator scenarios specific to visually degraded environments. NASA and 711 HPW/RHA are planning the appropriate resourcing necessary to accomplish these experiments prior to the end of the Technology Development phase of the program.

d. A consortium of appropriate organizations has been formed to ensure that the right technologies will be developed to ensure that future program efforts accurately emulate operational environments and benefit the pilot community as well as the AFMS.

e. Cost analysis is sufficient to determine the affordability of the program.

OBVA provides a way to measure the operational effects of visual characteristics in a controlled, repeatable manner. OBVA is a laboratory that will simulate the operational environment encountered by the pilot and measure the effects of changes in visual parameters. Unlike current training simulators, OBVA will provide a realistic visual setting allowing performance to be measured and its correlation to clinical measures of vision to be analyzed. This approach means that standards, waivers, and adoption of new visual appliances and procedures are made on a scientific basis that is applicable to the operational environment. OBVA will address the simulator hardware, operational scenario software, and correlation between clinical and operational measurements.

Table of Contents

List of Tables

Revision History

Change Number	Date of Change	Date Entered	Name of Person Making Change

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1. Capability Discussion.

1.1. There has been no systematic scientifically-based study of the relationship between clinical measures of vision, Air Force vision standards, and operational visual performance. Nor have there been any scientifically-based studies to determine the sensitivity of operational performance to changes in visual parameters. There is no tool available to determine these relationships largely because technology was not able to provide repeatable, high fidelity mission profiles that allowed analysis of the effects of variations of individual visual parameters on operational performance. Technology has matured to the point that vision parameters can be analyzed for their effect on performance. The Operational Based Vision Assessment (OBVA) program will provide a tool that will enable researchers to analyze these relationships leading to Air Force vision standards that are operationally based.

1.2. The tool will be in the form of a stand-alone laboratory with the capability to present high fidelity operational scenarios, control visual parameters within the scenarios, and record and analyze pilot performance and response. The operational environment for the laboratory will be an indoor, climate-controlled laboratory environment. OBVA is a stand-alone laboratory and not part of a Family of Systems or System of Systems.

2. Analysis Summary.

2.1. OBVA had a feasibility study that started in 2005. The study was been conducted jointly by NASA Ames Research Center and 711 HPW/RHA. There were several objectives for the feasibility study including: evaluation of projectors to determine whether acuity goals can be reached; characterization of luminance, contrast, resolution, edge blending distortion correction and light scatter; development of visual acuity tasks; development of a database for contrast and color; and development of a single channel, single projector, single image generator system to demonstrate feasibility. At the completion of the feasibility phase, the components were assessed to have a technological maturity sufficient to support a decision to proceed to full scale development of OBVA.

2.2. The subsequent Technology Development phase begun after a positive Milestone A decision in August 2008 has developed experiments to quantitatively correlate clinical vision measures with operational performance and continued the surveillance of technology. Simulation technology has made tremendous strides and NASA and AFRL designed experiments will be complete prior to a Milestone B decision planned for mid-2010.

2.3. An independent analysis conducted in late 2008 for AF/SGR by Milestones—the critical thinking company came to the same conclusion.

3. Concept of Operations Summary (CONOPS).

3.1. OBVA supports the AFMS Modernization Initiative on "Super-Vision". OBVA will provide the objective data on the relationship of clinically measured visual characteristics to flight performance. This data can be used to support current visual standards or support changes to those standards. Although OBVA will be used primarily to measure visual performance of a wide range of individuals with varying visual characteristics to determine the best visual

requirements for Air Force pilots, it could also be used to objectively measure visual performance after the use of surgery, drugs, or optical appliances.

3.2. OBVA is a vision laboratory. It will provide the capability to use high fidelity simulations to determine those visual characteristics that lead to the highest performance in realistic operational scenarios. The OBVA laboratory requires high resolution visual projectors, a realistic visual environment in which to immerse subjects, realistic computer-based operational scenarios that isolate specific visual characteristics, and state-of-the-art data acquisition equipment to record subject interactions with the environment.

3.3. The operational outcome provided by the OBVA laboratory is an objective measurement of the relationship between clinically measured visual characteristics and performance of simulated operational maneuvers and tasks. (This relationship can then be used, if desired, to adjust visual standards for current or future Air Force pilots.) OBVA is not a flight training simulator (although it uses similar components) and, at this time, it is not an evaluation tool to be used to measure the characteristics of individual pilots to determine their aeromedical fitness for flying duty.

4. Threat Summary.

4.1. OBVA is not likely to be a target because it will be housed on an Air Force base in CONUS. However, damage to the electrical power distribution system to the base will have the same effect as direct collateral damage to the OBVA laboratory. OBVA does not have a direct effect on Air Force operational missions so its temporary loss due to external or internal problems will not affect mission accomplishment. Even so, development of OBVA will seek to minimize the risk of temporary loss.

5. Program Summary.

OBVA is not part of a Family of Systems (FoS) or System of Systems (SoS). It is a one-of-a-kind laboratory system and it will be fully operational at the completion of its development. It will be developed entirely by government entities, NASA Ames and 711 HPW/RHA, using commercial-off-the-shelf (COTS) or modified COTS technologies. System hardware components will be acquired through commercial buys and assembled by OBVA government partners. Scenario development to inject both operational realism and scientific validity into visual assessments is part of the Technology Development phase. The software required for the scenarios is not COTS and will be developed by the government partners for each individual scenario. Scenario development will continue past the initial acquisition of the OBVA laboratory. Future experiments using the laboratory will require their own special software that will need to be developed prior to conducting the experiment.

6. System Capabilities Required for the Current Increment.

Threshold requirements are designated by [T] and the objective requirements are designated by [O]. The threshold and objective requirements shown here are for the maximum capability of the system. For some experiments the system may be used at settings that are below threshold values. That is perfectly admissible as those experiments may not need or desire maximum

system capability. Each system attribute will be demonstrated independently of the other attributes unless it is noted differently in the attribute rationale.

6.1. Key Performance Parameters (KPPs).

6.1.1. Correlation of Visual Performance: OBVA will demonstrate the ability to measure real-world visual performance and analyze its statistically significant correlation to clinically measured visual parameters [T]=[O]. Rationale: The reason for the OBVA program is to relate clinically measured visual characteristics to real-world performance. The initial clinical measures to be tested are visual acuity, contrast sensitivity, and color vision.

6.1.2. Force Protection: OBVA will not prevent or mitigate hostile actions against personnel, resources, facilities, and/or critical information. Therefore, this KPP is not applicable.

6.1.3. Survivability: OBVA is a laboratory system and will only be manned in a laboratory setting. No part of its mission is to enhance personnel survivability. Therefore, this KPP is not applicable.

6.1.4. Sustainment: OBVA is a non-ACAT program. This KPP is not applicable.

6.1.5. Net-Ready: OBVA is a closed loop system and will not communicate with external sources. Therefore, this KPP is not applicable.

6.2. Visual System Attributes.

These attributes were chosen based on the desire to study visual acuity, contrast sensitivity, and color vision.

6.2.1. Limiting Spatial Resolution: Must provide limiting or spatial resolution of 0.5 arc-minute/pixel [T] (0.35 arc-minutes/pixel [O]). Spatial resolution will be defined using a 25% contrast criterion, and must be assessed in both the horizontal and vertical directions. Rationale: These resolutions are necessary to ensure that the system is eye-limiting (20/10) and has close correspondence with real-world views so that correct measurements of visual performance may be made.

6.2.2. Viewing Distance: Distance from the test subject to the screen must be 4 m [T] (6 m [O]). Rationale: The threshold distance is the minimum acceptable to ensure that far vision is being used during the experiments.

6.2.3. Field of View: Must provide maximum field of view 80 degrees vertical and 80 degrees horizontal [T] (120 degrees vertical and 135 degrees horizontal [O]). Rationale: This field of view is required in order to perform the full scope of tasks envisioned for the OBVA simulator.

6.2.4. Refresh Rate: The refresh rate must be 60 Hz [T] (120 Hz [O]). Rationale: A refresh rate lower than 60 Hz may introduce flicker and will limit the target speeds that can be accurately displayed. Even at 60 Hz, image doubling can occur for moving targets typically encountered in simulator applications.

6.2.5. On Time Temporal Resolution: The display must be capable of presenting light for no more than 4 msec [T] (2 msec [O]) during each 16.7 msec video frame. Rationale: This will reduce tracking blur and present a more realistic visual image to the test subject.

6.2.6. Luminance: Maximum luminance required is (100 cd/m^2 [T] and 200 cd/m^2 [O]). Rationale: Necessary to assess daytime visual performance.

6.2.7. Checkerboard Contrast Ratio: Must be able to achieve contrast ratio of 16:1 [T] 32:1 [O]. Rationale: When this is taken together with limiting or spatial resolution, it specifies the contrast envelope for the display system. The system must have a large envelope to simulate real-world scenes.

6.2.8. Blending: The blending of different parts of a scene generated by different projectors shall be automated and accomplished in 60 minutes [T] (30 minutes [O]). Rationale: The ability to blend different parts of a scene automatically is now COTS. This method of blending requires only minutes to achieve a proper looking scene while doing the same task manually may require many hours.

6.2.9. Greyscale Resolution: The required greyscale resolution is 8-bits (256 levels) [T] 12-bits (4096 levels) [O]. Rationale: This determines the number and step size of luminance levels that can be displayed between the maximum and minimum luminances. This is important when trying to simultaneously simulate texture at different mean luminances (such as sunlight and shadow in the same scene). It provides a more realistic visual experience.

6.2.10. Chromaticity Gamut: The red, green, blue and yellow aviation signal lights should be within 0.03 CIE u, v chromaticity units from the edge of the gamut triangle [T] or fall within the gamut [O]. Rationale: This increases the range of color that can be displayed providing a more realistic visual experience.

6.2.11. Color Uniformity Across Space: When a uniform image is displayed, the absolute value of the deviation from the mean, measured at all sample locations, shall not exceed 3 CIELab E^*_{ab} units [T] (1 CIELab E^*_{ab} unit [O]). Rationale: This provides a more realistic visual experience by maintaining color uniformity across a projected scene.

6.2.12. Luminance Uniformity Across Space (Deviation from mean value): When a uniform image is displayed, the absolute value of the deviation from the mean, measured at all sample locations, shall not exceed 3% [T] (2% [O]). Rationale: This provides a more realistic visual experience by maintaining luminance uniformity across a projected scene.

6.2.13. Spatial Resolution Uniformity Across Space: When spatial resolution is measured at a set of display positions, the absolute value of the deviation from the mean value must be < 15% [T] (5% [O]). Rationale: This provides a more realistic visual experience by maintaining spatial and contrast uniformity across a projected scene.

6.3. Image Generator and Host Computer System Attributes.

6.3.1. Limiting Spatial Resolution: The image generator shall support spatial resolution of 0.5 arc-minute/pixel [T] (0.35 arc-minute/pixel [O]). Rationale: These resolutions are necessary to ensure that the system is eye-limiting (20/10) and has close correspondence with real-world views so that correct measurements of visual performance may be made.

6.3.2. Video Refresh Rate: Each IG channel shall refresh at a minimum of 60 Hz [T] (120 Hz [O]). Rationale: A refresh rate lower than 60 Hz may introduce flicker . Even at 60 Hz, image doubling can occur for moving targets typically encountered in simulator applications.

6.3.3. Update Rate: The IG shall be capable of updating the computer generated scenery at a steady 60 Hz [T] (120 Hz [O]) rate under normal rendering conditions. Rationale: This update rate is necessary for visual effectiveness while operating within a flight crew environment. Additionally, higher update rates improve motion fidelity.

6.3.4. Channel Synchronization: All IG channels must be synchronized at the video level and update rate level [T]=[O]. The video level synchronization must be within 2-lines of accuracy [T] (synchronization will be accurate to at least one video line [O]). The video synchronization primitives shall be hardware based (not software only) [T]=[O]. The video synchronization source can be either external to the IG (e.g., genlock third party device) or internally generated by the IG itself [T]=[O]. Rationale: The OBVA IG will include many IG channels to make up the synthetic environment and these displays must appear to the pilot or crew as a single large display without any discontinuities or synchronization anomalies.

6.3.5. Triangle Processing: Each IG channel shall be capable of rendering a synthetic environment suitable for pilot training that contains 100,000 visible (textured and lighted) triangles [T], (one million triangles [O]) while maintaining required frame update rates. Rationale: The larger the number of triangles the greater the scene realism and detail.

6.3.6. Pixel Fill Rate Processing: Each IG channel shall provide pixel fill rates for 1-billion pixels per second [T] (10 billion [O]). Rationale: To achieve visual acuity, a high fill rate is required.

6.3.7. Full Scene Subpixel Anti-Aliasing: Each IG channel shall include 16-subpixel [T] (32 [O]), full scene anti-aliasing. Rationale: This will minimize sampling artifacts.

6.3.8. Depth Buffer Precision: Each IG channel shall provide fully automated depth buffer hardware that supports proper hidden line / hidden surface polygon processing within the synthetic environment. The accuracy of the depth buffer hardware is 32-bits with floating point precision ([T]=[O]). The depth buffer hardware should facilitate accurate occultation (no tearing due to lack of precision) with clipping planes as close as 0.5 foot from the eyepoint out to far clip planes at 80 nautical miles (nm) from the eyepoint ([T]=[O]). Rationale: This enables the IG to determine the closer of two objects and render a scene without the artifact of the objects flickering back and forth.

6.3.9. Color Resolution: The IG hardware shall provide 32-bit color (8-bits R-G-B-A) [T]=[O]. The IG hardware shall support 10-bits per color component in OTW visual modes and 16-bit monochrome when sensor simulation is required [T]=[O]. The IG shall facilitate user defined gamma definitions for third party display tuning [T]=[O]. Rationale: This minimizes rendering artifacts associated with limited color space models.

6.3.10. Color Models: The IG manufacturer's specifications must list all color space models supported by that IG [T]=[O]. Rationale: Understanding the color space used by the IG is essential for proper planning and tuning purposes for third party OBVA projection and display systems / technology (color, contrast, …). This supports the Chromaticity Gamut attribute of the visual system.

6.3.11. Dedicated Ethernet for Host-IG Communications: The IG shall include one dedicated Ethernet network interface controller (NIC) for supporting data communications to and from the

IG and the remote host computer. NIC speed shall be 1-Gbit/second and support the TCP-IP protocol with UDP broadcast capabilities ([T]=[O]). Rationale: This is an industry standard.

6.3.12. CIGI Host-IG Communications Software: The host-IG NIC shall support the latest version of the Common Image Generator Interface (CIGI) data protocol for all run-time control of the IG ([T]=[O]). Rationale: This is an industry standard. The IG and host computer are independent of each other and each must be able to run the latest CIGI software.

6.3.13. CIGI Traffic Capture, Filter and Playback: The host-IG shall include the capability to capture in real-time and without affecting IG performance all network traffic between the host and IG for analysis purposes. The captured CIGI data may also be used by the IG to play back for technical support and/or demonstration purposes when the host is not in primary use. The IG operator shall have explicit control over which CIGI packets the IG shall use (or ignore) for diagnostic and/or technical support reasons with the IG manufacturer. ([T]=[O]) Rationale: This allows for replay for scientific analysis of the completed mission.

6.3.14. GPU Memory: Each Graphics Processing Unit (GPU) that is used for real-time rendering shall include onboard GPU memory of 4GB [T] (8GB [O]), to support advanced shader and 3D graphics intensive per pixel or per vertex processing chores. Rationale: This enables the IG rendering subsystem GPU(s) to have sufficient on-board GPU memory to also support very high resolution displays (e.g., 4096x2160) while simultaneously supporting all advertised GPU special effects.

6.3.15. CPU Memory: Each general purpose CPU used in the IG shall support the x86 (32-bit) Intel instruction set architecture [T]. The CPUs within the IG system shall support a 64-bit Intel instruction set architecture with support for 64-bit operating systems and multiple cores [O]. Rationale: This will help facilitate multi-threaded or multi-process IG algorithms on the CPU and it is an industry standard.

6.3.16. Online Disk Storage (Size): The IG shall include sufficient local, online disk storage with a capacity of at least 1TB [T] (2TB [O]). Rationale: This will support storage of a large scene database. Ideally, the IG operating system and runtime software shall be wholly separate from the data partition so a cold start process may be done on either without adversely affecting the other.

6.3.17. Online Disk Storage (Speed): The online IG disk storage system and runtime software shall support real-time paging to/from the online storage system while maintaining expected rendering frame rates of 60 Hz [T] (120 Hz [O]). Rationale: The storage system cannot slow the IG update rate.

6.3.18. Online Disk Storage (Reliability): The system software partition shall include RAID-1 (mirror) support to help safeguard against single disk failures [T] (Raid-5 [O]). The remaining IG data (if a separate volume) shall be RAID-5 [T]=[O]. Rationale: This will provide for high reliability for the storage system.

6.3.19. Texture Size: The IG hardware shall support mip-mapped texture maps up to 4096x4096 RGBA texels (4-component) in size [T] (32768x32768 texels [O]) for terrain modeling purposes. Rationale: This will provide for improved scene realism and simplified terrain modeling.

6.3.20. Terrain Levels of Detail: The IG shall include the runtime capabilities to automatically fade or morph between adjacent levels of detail for all terrain databases without any distracting artifacts (e.g., popping LODs or other artifacts must be avoided) [T]=[O]. Further, the IG shall be capable of rendering significantly large areas of the synthetic environment (e.g., a geocell or more) when required with at least 1-meter texel resolution for intended operations near the ground (i.e., (Geotiff imagery) [T]. The IG shall support real-time rendering from source materials with 1-foot texel resolution in the original Geotiff imagery materials consistent with real-time operations and system capacities on the IG [O]. Rationale: Meets the visual requirements specified above.

6.3.21. Moving Model Levels of Detail: The IG shall include the runtime capabilities to automatically fade or morph between adjacent levels of detail for moving models without any distracting artifacts (e.g., popping LODs or other artifacts must be avoided) [T]=[O]. Moving model detail should be capable of providing detail down to an inch of sufficient for taxiing, landing, formation flight and/or refueling operations (very close proximity to moving objects) [T]=[O]. Rationale: Meets the visual requirements specified above.

6.3.22. Cultural Detail: The IG shall support the ability to populate the synthetic environment with very large numbers of fixed cultural elements to maximize scene realism, consistent with inherent IG runtime capabilities, system capacities and specified real-time performance. Fixed and moving cultural detail should be capable of providing detail down to an inch of accuracy sufficient for taxiing, landing, formation flight and/or refueling operations (very close proximity to moving objects) [T]=[O]. Rationale: Meets the visual requirements specified above.

6.3.23. Cold Start: The IG system and runtime software, and all other data on the IG system, shall be capable of being fully restored to the original software / data state consistent with the original IG delivery and acceptance tests. A complete cold-start of the IG shall take no more than 10-hours to complete [T]=[O]. Rationale: This enables the IG to recover from hardware failures easily.

6.3.24. IG Startup Time: The IG shall start-up from a power-off condition to a 'ready for training' visual status in less than 10-minutes [T] (5 minutes [O]). Rationale: This provides time savings to staff start the IG.

6.3.25. Graceful Shutdown due to Power Interruption: The IG system software shall be capable of graceful shutdown in the event of a loss of power or brown-out in the simulation facility [T]=[O]. Rationale: This is essential to avoid catastrophic damage to the boot sectors of the hard drive subsystem rendering the IG unbootable.

6.3.26. Anti-Virus / Malware Protection Software: The IG should include appropriate anti-virus and malware protection software to avoid accidental corruption of the IG system [T]=[O]. Rationale: Prevents accidental corruption of the IG system during system maintenance, planned updates, or other unforeseen circumstances.

6.3.27. Maintainability: The IG shall include the capability to load new IG databases, models and/or system or new runtime software / firmware (to include regular updates to protective software) in the field [T]=[O]. Hardware facilities to help support these activities should include one read-write DVD/CD subsystem accessible via the IG console system [T]=[O]. Rationale:

Upgrades to the IG should be simple and inexpensive and not necessarily require the support of the IG manufacturer.

6.3.28. System Support: The IG manufacturer's run-time software shall be included with the IG system along with all standard diagnostics, manuals and other electronic media from the manufacturer (e.g., PDF or other suitable format) [T]. The IG can be operated and programmed without using the standard manufacturer's run-time software rather using third party or open-source scene graph software such as Open Scene Graph (OSG) and the IG can also be used to operate third party 3D graphics tools and programs that are implemented using industry standard OpenGL and advanced shader packages such as OpenGL shading language [O]. Rationale: This provides an IG with maximum flexibility. It enables OBVA to have an IG with open architecture permitting it to be programmed with software generated internally or from other vendors.

6.3.29. Host Computer: In addition to above requirements, the host computer shall be compatible with the IGs and cockpit system and demonstrate the ability to manage ownership and target functions [T]=[O]. Rationale: Host computer selection will be based on system size, number of IGs and other parameters. A compatible host can be procured commercially and there is no need to specify requirements beyond the capability discussed in this paragraph.

6.4. Cockpit System Attributes.

6.4.1. Motion: Motion is not desired [T]. The seat is equipped with a small displacement shaker [O]. Rationale: For OBVA motion is not necessary to determine visual performance but some minor motion on the cockpit seat is desirable for added realism.

6.4.2. Reconfigurable: Single color display (glass cockpit) that allows cockpit instrumentation to be able to be reconfigured through the use of software to simulate different aircraft (to include generic fixed or rotary wing aircraft) [T]. Two color displays and software allowing buttons and switches to turn and move on the displays [O]. Rationale: While the cockpit in the OBVA system is not designed for a specific aircraft nor is it intended to be high fidelity, some scenarios may require a degree of fidelity for specific aircraft.

6.4.3. Communication: There must be standard aviation headphones for communication between the cockpit and console operator [T]=[O]. Rationale: Simulates the real environment and allows for a simple method of communication during experiments.

6.4.4. Interface Capability (Preferred Option): OVBA should have the capability to interface with other cockpits that are high fidelity and/or platform specific [T]=[O]. Rationale: During the course of experimentation in the OBVA laboratory it may be necessary to incorporate high fidelity and/or platform specific cockpits into the experiments. OBVA should have the capability to interface with these kinds of cockpits.

6.4.5. Eye Tracking (Preferred Option): OBVA should be equipped with hardware and software required to perform eye tracking of test subjects [T]=[O]. Rationale: Some experiments that will be performed using the OBVA will track test subjects' eye movements relating to target acquisition and tracking.

6.5. Data Collection System Attributes.

6.5.1. Data Collection: The data collection subsystem shall be compatible with the IGs, host computer and cockpit system and demonstrate the ability to collect and store data at the speeds with which those subsystems operate [T]=[O]. Rationale: Data collection selection will be based on system size, number of IGs and other parameters. A compatible data collection subsystem can be procured commercially and there is no need to specify requirements beyond the capability discussed in this paragraph.

6.6. OBVA KPP Summary Table.

Para graph	Key Performance Parameter	Development Threshold	Development Objective	Rationale and References
6.1.1.	Correlation of Visual Performance	OBVA will demonstrate the ability to measure real-world visual performance and analyze its statistically significant correlation to clinically measured visual parameters.	T=O	The reason for the OBVA program is to relate clinically measured visual characteristics to real-world performance. The initial clinical measures to be tested are visual acuity, contrast sensitivity, and color vision.
6.1.2.	Force Protection	N/A	N/A	OBVA will not prevent or mitigate hostile actions against personnel, resources, facilities, and/or critical information.
6.1.3.	Survivability	N/A	N/A	OBVA is a laboratory system and will only be manned in a laboratory setting. No part of its mission is to enhance personnel survivability.
6.1.4.	Sustainment	N/A	N/A	OBVA is a non-ACAT program.
6.1.5.	Net-Ready	N/A	N/A	OBVA is a closed loop system and will not communicate with external sources.

Table 6.1. Key Performance Parameter Summary Table.

6.7. Visual System Attributes Summary Table.

Parag raph	Attribute	Development Threshold	Development Objective	Rationale and References

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
6.2.1.	Limiting Spatial Resolution	0.5 arc-minute/pixel (horizontal and vertical directions)	0.35 arc-minutes/pixel (horizontal and vertical directions)	These resolutions are necessary to ensure that the system is eye-limiting (20/10) and has close correspondence with real-world views so that correct measurements of visual performance may be made.
6.2.2.	Viewing Distance (test subject to screen)	4 m	6 m	The threshold distance is the minimum acceptable to ensure that far vision is being used during the experiments.
6.2.3.	Field of View (maximum)	+/- 40 degrees vertical and +/- 40 degrees horizontal	+/- 60 degrees vertical and +/- 67.5 degrees horizontal	This field of view is required in order to perform the full scope of tasks envisioned for the OBVA simulator.
6.2.4.	Refresh Rate	60 Hz	120 Hz	A refresh rate lower than 60 Hz may introduce flicker and will limit the target speeds that can be accurately displayed. Even at 60 Hz, image doubling can occur for moving targets typically encountered in simulator applications.
6.2.5.	On Time Dynamic Spatial Resolution	<4 msec at the beginning of each 16.7 msec video frame	<2 msec at the beginning of each 16.7 msec video frame	This will reduce tracking blur and present a more realistic visual image to the test subject.
6.2.6.	Luminance (maximum)	100 Cd/m2	200 Cd/m2	Necessary to assess daytime visual performance.
6.2.7.	Checkerboard Contrast Ratio	16:1	32:1	When this is taken together with limiting or spatial resolution, it specifies the contrast envelope for the display system. The system must have a large envelope to simulate real-world scenes.
6.2.8.	Blending	Automated	T=O	The ability to blend different parts of a scene automatically is now COTS.

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
				This method of blending requires only minutes to achieve a proper looking scene while doing the same task manually may require many hours.
6.2.9.	Greyscale Resolution	8-bits (256 levels)	12-bits (4096 levels)	This determines the number and step size of luminance levels that can be displayed between the maximum and minimum luminances. This is important when trying to simultaneously simulate texture at different mean luminances (such as sunlight and shadow in the same scene). It provides a more realistic visual experience.
6.2.10.	Chromaticity Gamut	The red, green, blue, and yellow aviation signal lights should be within 0.03 CIE u, v chromaticity units from the edge of the gamut triangle.	The red, green, blue, and yellow aviation signal lights should fall within the gamut.	This increases the range of color that can be displayed providing a more realistic visual experience.
6.2.11.	Color Uniformity Across Space	<3 CIELab E*ab units	<1 CIELab E*ab unit	This provides a more realistic visual experience by maintaining color uniformity across a projected scene.
6.2.12.	Luminance Uniformity Across Space (Deviation from mean value)	< 3%	< 2%	This provides a more realistic visual experience by maintaining luminance uniformity across a projected scene.
6.2.13.	Spatial Resolution Uniformity	< 15%	< 5%	This provides a more realistic visual experience by maintaining spatial and contrast uniformity

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
	Across Space			across a projected scene.

Table 6.2. Visual System Attributes Summary Table.

6.8. Host Computer System Attributes Summary Table.

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
6.3.1.	Limiting Spatial Resolution	0.5 arc-minute/pixel (horizontal and vertical directions)	0.35 arc-minutes/pixel (horizontal and vertical directions)	These resolutions are necessary to ensure that the system is eye-limiting (20/10) and has close correspondence with real-world views so that correct measurements of visual performance may be made.
6.3.2.	Video Refresh Rate	60 Hz	120 Hz	A refresh rate lower than 60 Hz may introduce flicker. Even at 60 Hz, image doubling can occur for moving targets typically encountered in simulator applications.
6.3.3.	Update Rate	60 Hz	120 Hz	This update rate is necessary for visual effectiveness while operating within a flight crew environment. Additionally, higher update rates improve motion fidelity.
6.3.4.	Channel Synchronization	(1) All IG channels synchronized at video and update rate levels (2) Video level synchronization within 2-lines of accuracy (3) Video synchronization primitives shall be hardware based (not	(1) T=O (2) Video level synchronization within 1-line of accuracy (3) T=O	The OBVA IG will include many IG channels to make up the synthetic environment and these displays must appear to the pilot or crew as a single large display without any discontinuities or synchronization anomalies.

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
		software only) (4) Video synchronization source can be either external to the IG or internally generated by the IG itself	(4) T=O	
6.3.5.	Triangle Processing	100,000 visible (textured and lighted) triangles	1,000,000 visible (textured and lighted) triangles	The larger the number of triangles the greater the scene realism and detail.
6.3.6.	Pixel Fill Rate Processing	1-billion pixels per second per channel	10-billion pixels per second per channel	To achieve visual acuity, a high fill rate is required.
6.3.7.	Full Scene Subpixel Anti-Aliasing	16-subpixel full scene anti-aliasing per channel	32-subpixel full scene anti-aliasing per channel	This will minimize sampling artifacts.
6.3.8.	Depth Buffer Precision	(1) Accuracy of the depth buffer hardware is 32-bits with floating point precision (2) Facilitate accurate occultation (no tearing due to lack of precision) with clipping planes as close as 0.5 foot from the eyepoint out to far clip planes at 80 nautical miles (nm) from the eyepoint	(1) T=O (2) T=O	This enables the IG to determine the closer of two objects and render a scene without the artifact of the objects flickering back and forth.
6.3.9.	Color Resolution	(1) 32-bit color (8-bits R-G-B-A) (2) Support 10-bits per color component in OTW visual modes and 16-bit monochrome	(1) T=O (2) T=O	This minimizes rendering artifacts associated with limited color space models.

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
		when sensor simulation is required (3) Facilitate user defined gamma definitions for third party display tuning	(3) T=O	
6.3.10.	Color Models	IG manufacturer's specifications must list all color space models supported by that IG	T=O	Understanding the color space used by the IG is essential for proper planning and tuning purposes for third party OBVA projection and display systems / technology (color, contrast, …). This supports the Chromaticity Gamut attribute of the visual system.
6.3.11.	Dedicated Ethernet for Host-IG Communications	The IG shall include one dedicated Ethernet network interface controller (NIC) for supporting data communications to and from the IG and the remote host computer. NIC speed shall be 1-Gbit/second and support the TCP-IP protocol with UDP broadcast capabilities.	T=O	This is an industry standard.
6.3.12.	CIGI Host-IG Communications Software	The host-IG NIC shall support the latest version of the Common Image Generator Interface (CIGI) data protocol for all run-time control of the IG.	T=O	This is an industry standard. The IG and host computer are independent of each other and each must be able to run the latest CIGI software.
6.3.13.	CIGI Traffic Capture,	The host-IG shall include the capability to capture in real-time	T=O	This allows for replay for scientific analysis of the

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
	Filter and Playback	and without affecting IG performance all network traffic between the host and IG for analysis purposes.		completed mission.
6.3.14.	GPU Memory	4GB	8GB	This enables the IG rendering subsystem GPU(s) to have sufficient on-board GPU memory to also support very high resolution displays (e.g., 4096x2160) while simultaneously supporting all advertised GPU special effects.
6.3.15.	CPU Memory	Support the x86 (32-bit) Intel instruction set architecture	Support a 64-bit Intel instruction set architecture with support for 64-bit operating systems and multiple cores	This will help facilitate multi-threaded or multi-process IG algorithms on the CPU and it is an industry standard.
6.3.16.	Online Disk Storage (Size)	1 TB	2 TB	This will support storage of a large scene database. Ideally, the IG operating system and runtime software shall be wholly separate from the data partition so a cold start process may be done on either without adversely affecting the other.
6.3.17.	Online Disk Storage (Speed)	60 Hz rendering frame rate	120 Hz rendering frame rate	The storage system cannot slow the IG update rate.
6.3.18.	Online Disk Storage (Reliability)	RAID-1 (mirror) support to help safeguard against single disk failures	RAID-5 for remaining IG data (if a separate volume)	This will provide for high reliability for the storage system.
6.3.19.	Texture	4096x4096 RGBA texels to support mip-	32768 x 32768 texels	This will provide for improved scene realism and simplified

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
	Size	mapped texture maps		terrain modeling.
6.3.20.	Terrain Levels of Detail	(1) Runtime capabilities to automatically fade or morph between adjacent levels of detail for all terrain databases without any distracting artifacts (e.g., popping LODs or other artifacts must be avoided) (2) Able to render significantly large areas of the synthetic environment (e.g., a geocell or more) when required with at least 1-meter texel resolution for intended operations near the ground (i.e., (Geotiff imagery)	(1) T=O (2) Support real-time rendering from source materials with 1-foot texel resolution in the original Geotiff imagery materials consistent with real-time operations and system capacities on the IG	Meets the visual requirements specified above.
6.3.21.	Moving Model Levels of Detail	(1) Runtime capabilities to automatically fade or morph between adjacent levels of detail for moving models without any distracting artifacts (e.g., popping LODs or other artifacts must be avoided) (2) Moving model detail should be capable of providing detail down to an inch of sufficient for taxiing, landing, formation flight and/or refueling operations (very close proximity	(1) T=O (2) T=O	Meets the visual requirements specified above.

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
		to moving objects)		
6.3.22.	Cultural Detail	Capable of providing detail down to an inch of accuracy sufficient for taxiing, landing, formation flight and/or refueling operations (very close proximity to moving objects)	T=O	Meets the visual requirements specified above.
6.3.23.	Cold Start	10 hours	T=O	This enables the IG to recover from hardware failures easily.
6.3.24.	IG Startup Time	10-minutes from a power-off condition to a 'ready for training' visual status	5 minutes	This provides time savings to staff start the IG.
6.3.25.	Graceful Shutdown due to Power Interruption	IG system software shall be capable of graceful shutdown in the event of a loss of power or brown-out in the simulation facility	T=O	This is essential to avoid catastrophic damage to the boot sectors of the hard drive subsystem rendering the IG unbootable.
6.3.26.	Anti-Virus / Malware Protection Software	Appropriate anti-virus and malware protection software	T=O	Prevents accidental corruption of the IG system during system maintenance, planned updates, or other unforeseen circumstances.
6.3.27.	Maintain-ability	(1) Capability to load new IG databases, models and/or system or new runtime software / firmware in the field (2) One read-write DVD/CD subsystem accessible via the IG console system	(1) T=O (2) T=O	Upgrades to the IG should be simple and inexpensive and not necessarily require the support of the IG manufacturer.

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
6.3.28.	System Support	Manufacturer's run-time software shall be included with the IG system along with all standard diagnostics, manuals and other electronic media from the manufacturer (e.g., PDF or other suitable format)	IG can be operated and programmed without using the standard manufacturer's run-time software rather using third party or open-source scene graph software such as Open Scene Graph (OSG) and the IG can also be used to operate third party 3D graphics tools and programs that are implemented using industry standard OpenGL and advanced shader packages such as OpenGL shading language	This provides an IG with maximum flexibility. It enables OBVA to have an IG with open architecture permitting it to be programmed with software generated internally or from other vendors.
6.3.29.	Host Computer	In addition to above requirements, the host computer shall be compatible with the IGs and cockpit system and demonstrate the ability to manage ownship and target functions.	T=O	Host computer selection will be based on system size, number of IGs and other parameters. A compatible host can be procured commercially and there is no need to specify requirements beyond the capability discussed in this paragraph.

Table 6.3. Host Computer System Attributes Summary Table.

6.9. Cockpit System Attributes Summary Table.

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
6.4.1.	Motion	Motion is not desired.	The seat is equipped with a small displacement shaker.	For OBVA motion is not necessary to determine visual performance but some minor motion on the cockpit seat is desirable for added realism.
6.4.2.	Reconfi-gurable	Single color display (glass cockpit) that allows cockpit instrumentation to be able to be reconfigured through the use of software to simulate different aircraft (to include generic fixed or rotary wing aircraft).	Two color displays and software allowing buttons and switches to turn and move on the displays.	While the cockpit in the OBVA system is not designed for a specific aircraft nor is it intended to be high fidelity, some scenarios may require a degree of fidelity for specific aircraft.
6.4.3.	Communication	There must be standard aviation headphones for communication between the cockpit and console operator.	T=O	Simulates the real environment and allows for a simple method of communication during experiments.
6.4.4.	Interface Capability (Preferred Option)	OVBA should have the capability to interface with other cockpits that are high fidelity and/or platform specific.	T=O	During the course of experimentation in the OBVA laboratory it may be necessary to incorporate high fidelity and/or platform specific cockpits into the experiments. OBVA should have the capability to interface with these kinds of cockpits.
6.4.5.	Eye Tracking	OBVA should be equipped with hardware	T=O	Some experiments that will be performed using the OBVA

Paragraph	Attribute	Development Threshold	Development Objective	Rationale and References
	(Preferred Option)	and software required to perform eye tracking of test subjects.		will track test subjects' eye movements relating to target acquisition and tracking.

Table 6.4. Cockpit System Attributes Summary Table.

6.10. Data Collection System Attributes Summary Table.

Paragraph	Key Performance Parameter	Development Threshold	Development Objective	Rationale and References
6.5.1.	Data Collection	The data collection subsystem shall be compatible with the IGs, host computer and cockpit system and demonstrate the ability to collect and store data at the speeds with which those subsystems operate.	T=O	Data collection selection will be based on system size, number of IGs and other parameters. A compatible data collection subsystem can be procured commercially and there is no need to specify requirements beyond the capability discussed in this paragraph.

Table 6.5. Data Collection System Attributes Summary Table.

7. Family of System and System of System Synchronization.

OBVA does not interface with any other Family of Systems or System of Systems. There are no other systems or programs supporting the OBVA CDD. Anticipated changes in Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF) are identified in paragraph 14.

Capability	CDD Contribution	Related CDDs	Related CPDs
		None	None

Table 7.1. Supported ICDs and Related CDDs/CPDs

8. Information Technology & National Security Systems Supportability.

Not Applicable.

9. Intelligence Supportability.

Not applicable.

10. Electromagnetic Environmental Effects and Spectrum Supportability.

Not Applicable.

11. Technology Readiness Assessment.

The following Technology Readiness Assessment was performed by the OBVA program team prior to the Milestone A decision of 12 August 2008. The following key technologies were examined: existing simulator systems, projectors, image generators (IGs), system integration capability (NASA Ames Research Center and 711 HPW/RHA), scenarios, and the OBVA system as a whole. A discussion of each key technology's score and the rationale for that score follows.

11.1. Existing Simulator Systems. Existing simulator systems have a Technology Readiness Level (TRL) of 9 (Actual system "flight-proven" through successful mission operations). These systems include projectors, IGs and additional hardware and software. Existing simulators are built and used every day so it is well known how to design and build these systems. OBVA will have different requirements but use the same system design.

11.2. Projectors. The high fidelity projectors that OBVA will use to project eye-limiting scenes are COTS with a TRL of 9. They are used in theaters, conference facilities, and simula-tors. While OBVA will stress their ability to limit visual artifacts, such as smear, the manufac-turers of these projectors are constantly making improvements to their ability to show high quality graphics.

11.3. Image Generators. IGs that have the power to generate and refresh the high fidelity scenes required to make OBVA eye-limiting are COTS with a TRL of 9.

11.4. System Integrators. The system integrators for OBVA, NASA Ames Research Center and 711 HPW/RHA, have years of experience designing and building flight simulators for a variety of applications. Their abilities are rated with a TRL of 9 because of this experience. OBVA will be a challenging design effort but these integrators have proven ability.

11.5. Scenarios. The scenarios presented in existing simulators depict many aspects of flight and air warfare and they have undergone years of development. The scenarios to be depicted by OBVA will tie clinical vision measures to operational performance and these have never been designed and proven—it is the purpose of OBVA as a research laboratory. Currently, these scenarios have been given a TRL of 2 (Technology concept and/or application formulated). As early scenarios are designed and begin to show the correlation between vision and performance, the TRL will increase. At the Milestone B decision point the TRL should be 5 (Component and/or breadboard validation in relevant environment). The development and success of these scenarios is essential to achieve the Key Performance Parameter for the OBVA system.

11.6. OBVA System. Because a system with OBVA's specific requirements has never been fabricated, it has a TRL of 2. As the components of the system are assembled and shown to work together, the TRL will increase and should be 5 at the Milestone B decision point.

12. Assets Required Achieving Initial Operational Capability (IOC).

Only one OBVA laboratory will be built. When that has been built and tested, personnel are trained, the training base is established, and the maintenance system is in place, IOC will have been achieved.

13. Schedule and IOC and Full Operational Capability (FOC) Definitions.

IOC and FOC are both scheduled for FY13 (October 2012). IOC and FOC will be achieved when the system is fielded, personnel are trained, training base is established, and maintenance system is in place.

14. Other Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF) and Policy Considerations.

OBVA is a one-of-a-kind laboratory system that will be deployed at only one location—an Air Force base in CONUS. The system will be quite large and require facilities to house the laboratory. Beyond that, the only base operating support required by OBVA is electricity and HVAC. While maintenance will need to be accomplished throughout the lifetime of the system, logistics issues are virtually non-existent because the technical staff that runs OBVA will also be capable of performing all necessary maintenance.

14.1. Doctrine: OBVA may impact current Air Force visual standards. Overarching doctrine changes likely won't be required.

14.2. Organization: The OBVA program will not drive changes in the current organizational structure.

14.3. Training: OBVA laboratory staff will consist of highly trained technical professionals. They will have been partners in the development of OBVA and should require no additional training to operate the system.

14.4. Materiel: The repair concept for OBVA would best be described as field maintenance. It will be repaired and maintained by laboratory personnel who are very well acquainted with the equipment that makes up the OBVA laboratory system.

14.5. Leadership and Education: The OBVA program will not drive changes in leadership, but will require changes in education for use and repair.

14.6. Personnel: OBVA will not drive personnel changes. OBVA will be operated, maintained, and sustained by DoD and contractor personnel with the appropriate aptitudes, knowledge, skill levels, AFSC structures, anthropometrics, and force management factors.

14.7. Facilities: OBVA will require a large dedicated room with appropriate space, lighting and electrical capabilities. These are not envisioned to require specialized capabilities.

14.8. Policy: No policy or public law changes are required.

15. Other System Attributes.

OBVA has several attributes that must be addressed in system design. These attributes include Human Systems Integration; Accessibility, and Environmental Quality.

Attribute	Development Threshold	Development Objective
Environmental Quality	Environmentally safe disposal.	Same
Human Systems Integration	Not adversely affect human systems. Human Systems Integration will be used to optimize the relationship between the human and the system.	Same
Accessibility	All parts must be easily accessible by operator and service personnel.	Same

Table 15.1. Other System Attributes.

16. Program Affordability.

Below is the current Operational Based Vision Assessment program funding profile. This profile is based on the current estimate of one required OBVA laboratory. Pending the outcome of this CDD and developmental actions, the funding profile will be adjusted to reflect the new requirements.

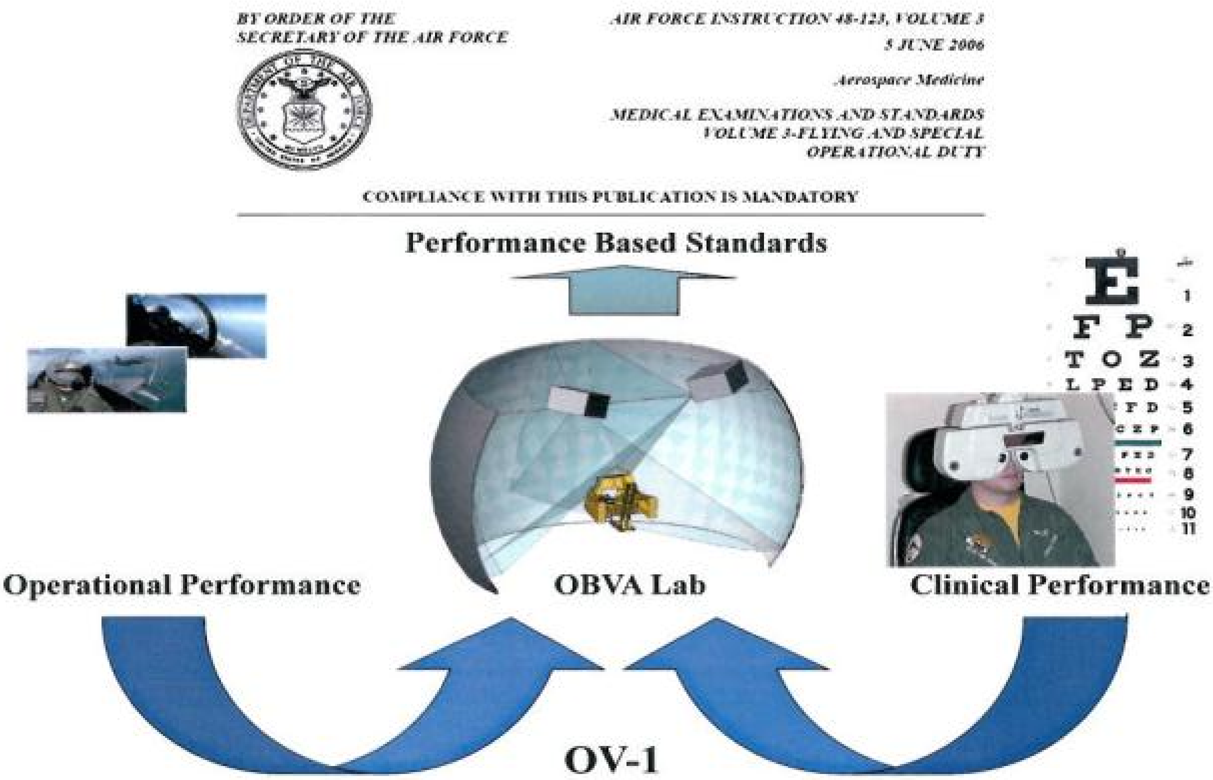
Current Program ($M)	FY08	FY09	FY10	FY11	FY12	FY13	FY14
3600 RDT&E	1.70	1.17	3.87	4.60	1.93	0.34	0.0

Table 16.1. Program Funding Profile.

17. The Way Ahead.

- CDD Approval – May 10
- Milestone B – Jun 10 (for initial system development)
- Milestone C – Oct 12
- IOC & FOC – Oct 12

Appendix A: Net-Ready KPP Products



Appendix B: References

1. AFI 10-601, Capabilities Based Requirements Development, 31 July 2006
2. DoD Directive 5000.01, The Defense Acquisition System, 12 May 2003
3. DoD Instruction 5000.02, Operation of the Defense Acquisition System, 8 December 2008
4. Federal Acquisition Regulation, http://www.arnet.gov./far/, 3 March 2004
5. AFI 48-123, Medical Examinations and Standards Volume 3 – Flying and Special Operational Duty, 24 September 2009

Appendix C: Acronym List

AF	Air Force
AFMS	Air Force Medical Service
AFRL	Air Force Research Laboratory
CDD	Capabilities Development Document
CONOPS	Concept of Operations
COTS	Commercial Off-the-Shelf
CPU	Central Processing Unit
DoD	Department of Defense
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership & Education, Personnel & Facilities
FOC	Full Operational Capability
FoS	Family of Systems
GPU	Graphics Processing Unit
HPW	Human Performance Wing
HSW	Human System Wing
IG	Image Generator
IOC	Initial Operational Capability
KPP	Key Performance Parameter
NASA	National Aeronautics and Space Administration
OBVA	Operational Based Vision Assessment
SoS	System of Systems
TRL	Technology Readiness Level
USAF	United States Air Force
[O]	Objective
[T]	Threshold

APPENDIX B

List of Presentations

Winterbottom, M., Gaska, J., Gooch, J., Wilkins, L., Gray, R. (2013). Operational Based Vision Assessment: Contrast and Motion Sensitivity. The Eye, The Brain & The Auto Research Congress.

Winterbottom, M., Gooch, J., Wright, S., Gaska, J., Gao, H., Lloyd, C., Hadley, S. (2012). Operational Based Vision Assessment (OBVA) Research Involving Depth Perception. Presentation at the International Congress on Aerospace Medicine, Melbourne, Australia.

Winterbottom, M., Gaska, J., Wright, S., Gooch, J. (2012). A Monte Carlo Simulation of Four Contrast Threshold Estimation Techniques: Clinical Vision Test Selection for Operationally-Based Vision Assessment. Poster presentation for Aerospace Medical Association Annual Meeting.

Archdeacon, J., Gaska, J., Timoner, S. (2012). An Operationally Based Vision Assessment Simulator for Domes.

Sweet, B., Kato, K. (2012). 120 Hz – the New 60 for Flight Simulation? Proceedings of the IMAGE Society Annual Conference.

Archdeacon, J., Iwai, N., Sweet, B. (2012). Designing and Developing an Image Generator for the Operational Based Vision Assessment Simulator. Presentation at AIAA Modeling and Simulation Technologies Conference, Minneapolis, MN.

Gaska, J., Gooch, J., Winterbottom, M. (2011). OBVA Operational Scenario Development. Presentation at Advanced Technology Applications for Combat Casualty Care (ATACCC).

Gaska, J., Winterbottom, M., Sweet, W., Rader, J. (2010) Pixel Size Requirements for Eye-Limited Flight Simulation. Proceedings of the IMAGE Society Annual Conference.

Gaska, J., Winterbottom, M., Gooch, J., Aaron, M., Clark, P., Rader, J., Sweet, W. (2010). Pixel Size Requirements for an Eye-Limited Flight Simulation Laboratory for Operational Based Vision Assessment. Aerospace Medical Association Annual Meeting.

Gaska, J., Winterbottom, M., Sweet, W., Rader, J. (2010) Pixel Size Requirements for Eye-Limited Flight Simulation. Proceedings of the IMAGE Society Annual Conference.

Gaska, J., Geri, G., Winterbottom, M. (2010). Operational Based Vision Assessment (OBVA) Flight Simulation Laboratory Development Specifications and Trade-Space Analyses. Warfighter Contract Technical Memorandum TO-10-2009.

Gaska, J., Clark, P., Winterbottom, M., Sweet, B., Gooch, J. (2009). Operationally Based Vision Assessment Laboratory Development. Aerospace Medical Association Annual Meeting.

Gaska, J., Clark, P., Winterbottom, M., Sweet, B., Gooch, J. (2009). The Effect of Blur on Landolt C Acuity and Aircraft Feature Identification. Aerospace Medical Association Annual Meeting.

Winterbottom, M., Gaska, J., Geri, G., Sweet, B. (2008). Evaluation of a Prototype Grating-Light-Valve Laser Projector for Flight Simulation Applications. Society for Information Display Digest, pp. 911-914.

LIST OF ABBREVIATIONS AND ACRONYMS

711 HPW	711th Human Performance Wing
AFB	Air Force Base
AFMS	Air Force Medical Service
AFRL	Air Force Research Laboratory
CDD	Capability Development Document
CDR	Critical Design Review
CIGI	Common Image Generator Interface
COTS	commercial-off-the-shelf
CPU	central processing unit
GPU	graphics processing unit
FSAA	full scene anti-aliasing
HD	high definition
IG	image generator/generation
IPT	Integrated Product Team
LCD	liquid crystal display
NASA-ARC	National Aeronautics and Space Administration-Ames Research Center
OBVA	Operational Based Vision Assessment
PDR	Preliminary Design Review
RHA	Human Effectiveness Directorate, Warfighter Readiness Research Division
USAF	United States Air Force